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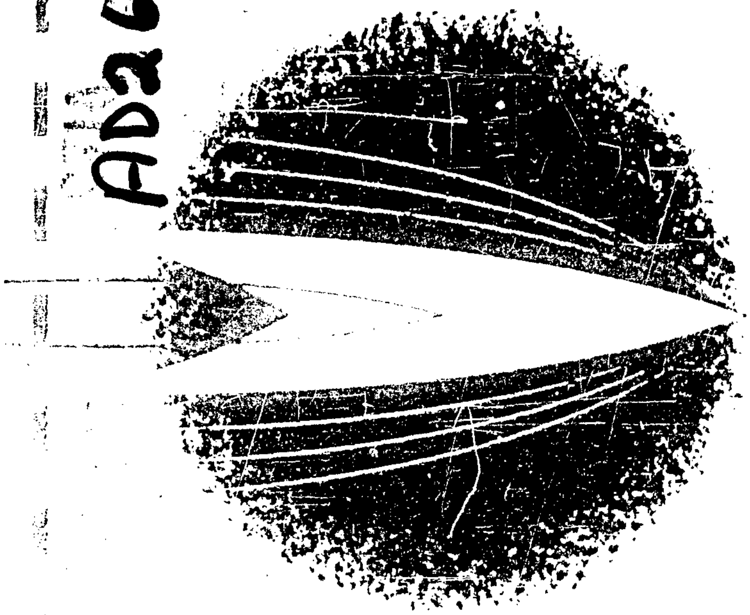

August 1961
Report No. 2092
(Annual Summary)
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STRESS-CORROSION CRACKING OF HIGH-STRENGTH ALLOYS

Contract DA-04-495-ORD-3069

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Structural Materials Division

Aerojet-General CORPORATION

THE GENERAL TIRE

A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

August 1961

Report No. 2092
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INVESTIGATION OF STRESS-CORROSION CRACKING OF HIGH-STRENGTH ALLOYS

Contract DA-04-495-ORD-3069

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FOREWORD

This report is based upon work performed on U.S. Army Ordnance Contract DA-04-495-ORD-3069. It covers the work period 1 July 1960 through 30 June 1961, which represents the first half of the contractual effort. The investigation was made at the Structural Materials Division Development Laboratories of Aerojet-General Corporation, Azusa, California.

This contract was administered under the direction of the U.S. Army Ordnance Corps., Frankford, Arsenal, with Mr. H. Rosenthal acting as Project Engineer.

The authors are gratefully indebted to Dr. E. H. Phelps and Mr. A. W. Loginow of the United States Steel Corporation for their invaluable technical assistance in the design of the test fixtures and the methods used in this investigation.

ABSTRACT

Six high-strength alloys were evaluated for stress-corrosion susceptibility in environments representative of those environments to which the alloys are normally exposed during the manufacture, hydrostatic testing, and storage of solid-rocket-motor cases. The alloys were heat-treated or cold-rolled to yield strengths ranging from 194,000 to 278,000 psi. The environmental stress-corrosion studies were conducted with bent-beam and U-bend specimens, with the bent-beam specimens stressed to 75% of the yield strength. Significant failures were observed with the Ladish D6AC, Type 300M, and Vascojet 1000 alloy steels in the environments of distilled water, tap water, salt water, and high humidity. The Vascojet 1000 alloy was the most susceptible to stress-corrosion failure. No failures were observed with any of the other environments or alloys tested.

CONTENTS

CONTENTS (cont.)

CONTENTS (cont.)

CONTRACT FULFILLMENT STATEMENT

This annual summary report is submitted in partial fulfillment of the contract.

I. INTRODUCTION

This history of rocket development and the present-day urgency associated with reliability and performance of rocket systems attest to the fact that high standards in all critical areas must be raised even higher for further advancement. The efficiency required of ultra-high-thrust rocket motors designed to propel large payloads into space dictates that extreme measures must be taken in weight savings by reduction of non-payload weight.

In order to achieve some significant weight reduction of the mass of materials (non-payload weight) required to construct solid rocket cases, high-strength alloys have been developed. At the present time, the alloys in the high-strength category that have been most highly developed are of ferrous base. Low-alloy martensitic steel, silicon-modified 4300 series, hot-worked die, cold-worked precipitation-hardened (PH) stainless steel comprise the classes of steels that fall within the high-strength category. In the lightweight, high-strength category are the titanium alloys.

Although these alloys have excellent mechanical properties and are capable of meeting designs with high stress requirements, their performance reliability is not always satisfactory.

Frequently, during hydrostatic and other pressurization testing, premature failures are experienced. These failures occur with presumably metallurgically sound pressure vessels. Analyses of these failures indicate that stress corrosion invariably is the causitive mechanism.

This program is designed to study the susceptibility to stress corrosion of high-strength alloys contemplated for use as rocket-motor case materials. The candidate materials were exposed to environments that are representative of those that would exist during some phase of the manufacturing, testing, and long-term storage of solid rocket chambers.

The effect of material parameters such as composition, strength level, welding, microstructures, and surface conditions on stress corrosion were explored in this investigation.

II. DISCUSSION

Broadly, the term stress corrosion includes any combined effect of stress and corrosion on the behavior of materials. The principal factors involved in stress-corrosion cracking are stress, environment, time, and the internal structure of the material. The importance of these factors varies, and they may interact, one exhilerating the action of the other. If stress-corrosion cracking occurs, there must be tensile stresses at the surface. These stresses may be residual (internal) or applied. Generally, internal stresses are produced by non-uniform deformation of the metal during cold working, by unequal cooling from high temperatures, and by internal structural rearrangements involving volume changes. These concealed stresses generally are of greater importance than applied stresses, especially in view of the factor of safety used in design of pressure vessels.

The magnitude of stresses varies from point to point within a stressed component, but in order to promote stress-corrosion cracking, tensile stresses in the neighborhood of the yield strength of the material are usually required. There are, however, reported failures that occur at applied stresses well below the yield strength of the metals.

Stress-corrosion cracking has been observed in almost all metal systems; yet, for each metal or alloy, stress-corrosion cracking is associated with specific environments. The environments that induce cracking usually attack the metal in a superficial manner when stresses are absent.

The time to stress-corrosion failure of metallic components may vary from minutes to years, but accelerated laboratory tests may be employed to study the relative susceptibility to the stress-corrosion cracking of numerous alloys.

III. EXPERIMENTAL PROCEDURE AND RESULTS

A. ALLOYS AND ENVIRONMENTS TESTED

In accordance with the contractural agreement, six vacuum-melted alloys, representative of the following classes of rocket-motor-case materials, were procured and tested: low-alloy martensitic steel, silicon-modified 4300 series steel, hot-worked die steel, cold-worked PH steel, precipitation-hardening stainless steel, and a high-strength titanium alloy.

Twelve different environments were chosen as being typical of the natural environments to which the rocket-motor cases are exposed during fabrication, hydrostatic testing, and storage.

1. Specific Alloys and Producers

The specific alloys tested and the respective producers are as follows:

a. Ladish D6AC (low-alloy martensitic steel), Allegheney Ludlum Steel Corporation

b. Type 300M (silicon-modified 4300 series steel), Allegheney Ludlum Steel Corporation

c. Vascojet 1000 (hot-worked die steel), Vanadium Pacific Steel Company

d. AM355 (cold-worked PH steel), Wallingford Steel Company

e. PH 15-7 Mo (precipitation-hardening stainless steel), Wallingford Steel Company

f. B120VCA titanium (high-strength beta titanium alloy), Crucible Steel Company

Table 1 gives a comprehensive analytical summary of all six alloys.

2. Selection of Environments

The following environments were used to study the stress-corrosion-cracking susceptibility of the alloys tested.

a. Atmosphere (air) was used as a standard environment against which all of the other environmental tests could be compared.

b. Distilled water was also used as a standard environment against which all of the other environmental tests could be compared.

c. Tap water represents the medium frequently used to clean solid-propellant-rocket-motor cases. This fluid is also used in the hydrostatic testing of pressure vessels, particularly those chambers constructed of corrosion-resistant alloys.

d. Inhibited water (0.25% by weight sodium dichromate solution) represents the medium frequently used to flush solid-propellant-rocket-motor cases and in the hydrostatic testing of pressure vessels, particularly those constructed of low-alloy steels.

e. Heat-treating salt solution (1% by weight marquench salt solution), a mixture of nitrites and nitrates, is used as constant-elevated-temperature quenching media in the heat treatment of certain rocket-motor case materials.

f. Salt water (3% by weight sodium chloride solution) was used to simulate a moderately severe marine environment.

g. A chlorinated degreasing solvent (trichloroethylene) was chosen as a representative environment to test the effect of chlorinated degreasing solvents on rocket-motor-case materials.

h. A rust-inhibiting oil, E. F. Houghton's Cosmoline 377, conforming to MIL-C-14201A, Grade 2, was used as the rust preventive compound for rocket-motor cases during the manufacture, transit, and limited storage prior to propellant installation.

i. An aqueous soluble-oil solution (4% by volume Chevron soluole oil) represents one of the fluids used in the hydrostatic testing of pressure vessels, particularly those constructed of corrosion-resistant alloys.

j. The hydrocarbon-base oil represents a hydrostatic test fluid to replace aqueous solutions.

k. High humidity was used in accelerated testing to simulate severe atmospheric conditions.

l. Solid propellants often undergo a certain amount of decomposition during long-term storage of solid-propellant-rocket motors. The purpose of investigating this environment is to determine the role that the decomposition products of the solid propellants play in the stress-corrosion behavior of the rocket-motor-case materials.

Table 2 lists all of the chemicals used in the makeup of these environments and the source of each. Table 3 gives a typical analysis of tap and distilled water samples taken from the same sources as the water used in the environmental testing.

B. TEST PROCEDURES

Both bent-beam specimens (stressed to a predetermined level) and U-bend specimens were used in this investigation to determine the relative susceptibility to environmental stress-corrosion of the various high-strength alloys tested.

1. Specimen Preparation

Test specimens were prepared by blanking 1 x 8 in. coupons from sheet material of each alloy. The specimens were heat-treated to the desired strength levels and finish-ground to appropriate specimen thicknesses and lengths. The length of each specimen was determined from the yield strengths of the alloys and the specimen thickness in a manner described later in a section under "Stress Determinations."

The mechanical properties of each alloy were obtained by pulling tensile specimens (see Figure 1) on a Baldwin-Tate-Emery Universal testing machine. By employing a Peters Extensometer and a Baldwin stress-strain recorder, stress-strain curves were obtained from which the 0.2% offset yield strength was computed. In order that all of the alloys be put on an equal basis for comparison of the stress-corrosion test results, 0.2% offset yield strengths of 200,000 to 240,000 psi were aimed for in the ferrous-base alloys. The titanium was aged to give strength levels equivalent to those obtained in the steels on a strength-to-weight ratio basis.

After heat treating, the low-alloy steel specimens were prepared to 0.060 $\pm$0.005 in. thickness and a 32-rms finish by surface grinding. The edges were ground to give a specimen width of 1.00 in. The specimens were then cut into lengths to give a maximum surface tensile stress of 75% of the yield strength over a 7-in. span for the bent-beam tests. The stainless steel alloy specimens were prepared by shearing to a width of approximately 3/32 of an in. greater than 1 in., and then carefully grinding to 1.00 in. in width. Since the material was thin (0.030 to 0.040 in.), the shorter 4-in.-span test fixture was used. The specimens were cut into lengths to give a maximum surface tensile stress of 75% of the yield strength over a 4-in. span for the bent-beam test. As with the stainless steel alloys, the titanium alloy specimens were prepared by shearing to 1-in. widths and then grinding to lengths to give a maximum surface tensile stress of 75% of the yield strength over a 4-in. span for the bent-beam test.

The appropriate length of the specimens was determined by a relationship, shown graphically in Figure 2, between the strain in the outer fibers at the middle of the specimen, the specimen length, the specimen thickness, and the holder span. This relationship is based on the exact solution for an elastic beam. By assuming a constant modulus of elasticity and span length, Figure 2 was modified to produce the curves shown in Figures 3, 4, and 5. Figure 3 is the graph of tensile stresses in bent beams at varying lengths for various beam thicknesses, assuming the span to be 7.000 in. and the modulus of elasticity (for steel) to be 30×10^6 psi. Figure 4 illustrates the same relationship for steel beams over a 4-in. span, and Figure 5 for titanium beams over a 4-in. span.

In addition to the bent-beam specimens, U-bend specimens were also employed. These specimens were prepared by bending the specimen over 12T- and 24T-dia mandrels until the two sides were separated by a distance equal to the diameter of the mandrel; then, the specimen was held in a stressed condition by a bolt through holes drilled in each end (see Figure 6).

The heat-treat schedules and the mechanical properties of all of the alloys tested are summarized in Tables 4 through 9 and depicted graphically in Figures 7 through 13. Figure 14 illustrates some of the typical microstructures of the various alloys tested. The microstructures indicate that each alloy responded normally to the treatment it was given to produce the desired strength levels.

2. Testing Methods

In this investigation, it has been endeavored to reproduce as nearly as possible the environmental conditions that exist in the manufacturing, hydrostatic testing, and long-term storage of rocket-motor cases, and to study the susceptibility of several high-strength alloys to stress-corrosion cracking in the various environments. The environmental stress-corrosion studies were conducted with bent-beam and U-bend specimens, with the bent-beam specimens stressed to 75% of the yield strength.

A schematic diagram of the 304 stainless steel specimen holder used in the bent-beam tests is presented in Figure 15. The specimen holder and a specimen prior to stressing is shown in Figure 16. Figures 17 and 18 illustrate specimens stressed in the specimen holders.

The environmental stress-corrosion laboratory is shown in Figure 19, and Figure 20 is a detailed illustration of an environmental chamber.

3. Stress Determinations

The stress setup within an elastic body is proportional to the strain to which the body is subjected by the applied load according to Hooke's Law, which may be rewritten as

$$\text{stress} = k \times \text{strain}$$

where k is a constant for the material of the elastic body. This constant is known as the modulus of elasticity of the material, and for most steel alloys is generally taken as 30×10^6 psi.

Flat-beam specimens are used in the particular method and techniques employed in studying the stress-corrosion behavior of the alloys being investigated in this program. The amount of tensile stress induced in the specimen is directly proportional to the distance that the beam is deflected. This deflection, in turn, depends upon the length of the bent beam across a known distance. The stress can therefore be determined if both the length of the beam and the distance across which the beam is deflected are known.

The stresses were determined from tables of tensile stresses in bent beams as prepared by Dr. E. H. Phelps of the United States Steel Corporation.

In order to obtain a more accurate reading of the actual stresses obtained in the bent-beam specimens, Tatnall C6-141 foil-type strain gages, mounted longitudinally in the center of the top surface of selected specimens (see Figure 21), were used to make a spot check. The strain-gage readings were taken both before and after the specimens were stressed. The actual strain of the deflected beam was obtained in microinches, and the maximum induced tensile stress was computed by employing Hooke's Law. However, the values obtained by the strain-gage method were considerably higher than those calculated from the U.S. Steel tables (see Table 10).

A probable reason for the discrepancy observed between the theoretical and measured values lies in the fact that some plastic deformation of the specimens had occurred. Inspection of the stress-strain curves recorded during the mechanical testing of Vascojet 1000 tensile specimens reveal that the proportional limit of this alloy is about 50 to 60% of the 0.2% offset yield strength. Since the flat beams were bent to get a maximum tensile stress of 75% of the 0.2% offset yield strength, the proportional limit has been surpassed and some plastic deformation has occurred. Inasmuch as tables of tensile stresses in bent beams are valid only if stress does not exceed the proportional limit of the material, proper comparison cannot therefore be made between the theoretical and the measured strain values. Evidence of plastic deformation in the specimens is taken from the observation that the specimens do not return to their original flatness but retain a slight bow in the center.

C. ENVIRONMENTAL TEST RESULTS

In order to be better able to draw a clear comparison of all of the alloys tested, each environment will be treated individually. The bent-beam specimens were tested in triplicate and the U-bend specimens were tested in duplicate.

1. Air

Bent-beam specimens of each alloy were exposed in air for a period of four weeks. None of the specimens failed in this environment (see

Table 11). The average measured temperature of the air was 74°F, ranging from a low of 62°F to a high of 92°F. The measured relative humidity averaged 50%, ranging from a low of 16% to a high of 74%.

2. Distilled Water

In general, this environment was found to be the most corrosive of all the environments tested. The reasons for this are not clear. However, a comparison can be drawn between distilled water and tap water. Since distilled water is more acidic than tap water, it has a greater tendency to promote corrosion than does the tap water. The only alloy that failed in distilled water with the bent-beam specimens was Vascojet 1000. These failures occurred only at the higher strength levels (see Table 12). U-bend specimens of all three-low-alloy steels failed in distilled water. As was expected, Vascojet 1000 was the least resistant to stress-corrosion cracking (see Table 13). Red and black oxides of iron formed on all three of the low-alloy steels in the distilled water.

3. Tap Water

Failures with the Vascojet 1000 alloy bent-beam specimens and Vascojet 1000 and Type 300M alloy U-bend specimens were observed in tap water (see Tables 14 and 15). However, the time to failure was considerably longer than that of the distilled water. Again, iron oxides formed on all three of the low-alloy steels.

4. Sodium Dichromate Solution

None of the alloys failed in this environment in three weeks with either the bent-beam or with the U-bend test specimens (see Tables 16 and 17). This chromate solution inhibited the formation of any surface corrosion on the low-alloy steels.

5. Marquench Salt Solution

None of the alloys failed in this environment in three weeks with either the bent-beam or with the U-bend test specimens (see Tables 18 and 19). Some slight rusting of the Type 300M alloy specimens was observed.

6. Sodium Chloride Solution

Failures with the VascoJet 1000 alloy bent-beam specimens and all three low-alloy steel U-bend specimens were observed in this environment (see Tables 20 and 21). The time to failure was approximately the same as that of the distilled water. Table 20 shows some failures of the titanium alloy. However, this was attributed to faulty specimens and not to stress-corrosion cracking. Oxides of iron were noted on all three of the low-alloy steels.

7. Trichloroethylene

None of the alloys failed in this environment in three weeks with either the bent-beam or the U-bend test specimens (see Tables 22 and 23). Table 22 shows some failures of the titanium alloy. However, this was attributed to faulty specimens and not to stress-corrosion cracking.

8. Cosmoline

None of the alloys failed in this environment in three weeks with either the bent-beam or the U-bend test specimens (see Tables 24 and 25). Complete rust inhibition on the low-alloy steels was observed.

9. Soluble Oil Solution

None of the alloys failed in this environment in three weeks with either the bent-beam or the U-bend test specimens (see Tables 26 and 27). No corrosion of the low-alloy steels was observed.

10. Hydrocarbon-base Oil

No testing was accomplished in this environment.

11. High Humidity

Ladish D6AC steel was the only alloy tested in this environment. Bent-beam specimens of this alloy failed at the higher-strength levels (see Table 28). The humidity conditions consisted of air saturated with water vapor at 190°F ±15°F. Severe rusting of the specimens was observed.

12. Solid Propellants

No testing was accomplished in this environment.

D. DISCUSSION OF RESULTS

When a stress-corrosion failure occurs in the field, the first problem is one of diagnosis. It has been found that for each alloy, there are certain environments that induce stress-corrosion cracking. In the event of failure, the possibility of an environment known to promote cracking should be investigated. Unfortunately, it is not safe to assume that all other environments are ineffective.

There are several principles involved in reproducing stress-corrosion cracking failures in the laboratory. The first requirement is the reproduction of service conditions. However, surface stress conditions are often complex and not easily simulated. Also, tests must be of reasonable duration. Finally, putting a quantitative figure on the damage that has occurred in the test is not a simple matter. The most important factors are time, the nature of the stress, the condition of the metal, and the environment.

There are no universally accepted tests for determining susceptibility to stress-corrosion cracking. In most cases, the evaluation of stress-corrosion cracking is sought in tests in which, if complete fracture of the specimen occurs, the measurement recorded is the time for rupture to occur. Such has been the case in this investigation. It will be noted that most of the failures have occurred with the low-alloy steels, heat-treated to the higher-strength levels. These failures occurred only in aqueous environments to which no inhibitors had been added.

It is apparent from the environmental stress-corrosion test data presented herein that some alloys are more susceptible to stress-corrosion than others, and that some environments are more prone to cause stress corrosion than others. An analysis of the data will show that distilled water, tap water, salt water, and high humidity all caused some stress-corrosion failures with the low-alloy steels (Ladish D6AC, Type 300M, and Vascojet 1000). These failures occurred, without exception, at the higher end of the strength-level range. It follows from this that for any given environment and period of exposure, there exists a critical strength level above which failure will occur by the mechanism of stress corrosion, and below which no failures can be expected. After three weeks of exposure at a stress level of 75% of the 0.2% offset yield strength, the critical strength level of the Vascojet 1000 alloy lies between 212,000 and 238,000 psi for the environments listed above. For all of the other environments, it probably lies above 242,000 psi. At a stress level of 75% of the yield strength and an exposure time of three weeks, the critical strength levels of all of the other alloys in all of the environments tested lies above the highest yield strengths at which each alloy was tested. Similarly, critical strength levels of specimens stressed to 100% of the yield strength (such is the case with the U-band specimens) for a given environment and exposure period can be estimated from the test data.

There exists the possibility that large vessels undergoing hydrostatic testing contain microcracks which lead to rapid failure because of high notch sensitivity. These microcracks very often escape detection. Other investigators have shown that notch-sensitive specimens produce relatively rapid failures. In addition, the possibility of brittle failure as caused by hydrogen embrittlement cannot be excluded. Further studies should be made on these considerations as possible causes of catastrophic failures.

Some typical failures of the Vascojet 1000 alloy specimens from distilled water, tap water, and salt water are illustrated in Figure 22. It will be noted that failure did not occur in the center of the specimen, where it was believed the highest stresses existed, but rather at a point somewhat removed from the center of the specimen. This lends further evidence to the phenomena that some plastic deformation had occurred while the specimen was being placed in the specimen holder. Figure 23 illustrates the fractured surface of a failed specimen, and the cross section of the fractured surface is shown in Figure 24.

One further item that merits consideration at this point is the effect of galvanic currents upon stress-corrosion failure. During the course of this investigation, the question was raised concerning the magnitude and the effects of the various alloys and the stainless steel specimen holders during environmental testing. Consequently, an investigation was conducted to determine just what this galvanic effect would be on the stress-corrosion failure of the alloys tested. The galvanic currents between Vascojet 1000 alloy specimens and one of the 304 stainless steel specimen holders was measured in tap water and distilled water. Virtually no potential was observed in the distilled water.

However, the tap water produced a potential of about 200 mv., the Vascojet 1000 being anodic to the 304 SS (see Figure 25).

IV. SUMMARY AND CONCLUSIONS

Based upon the screening tests performed during the first year's effort of this investigation, the following conclusions are drawn:

A. Stressed bent-beam specimens of Vascojet 1000 are more susceptible to stress-corrosion cracking than any of the alloys when tested at 75% of yield strength. This alloy is extremely susceptible to the corrosive action of distilled water, tap water, and a 3% solution of sodium chloride at ambient temperature. The threshold strength level of this material, based on these short-term tests, lies between 212,000 and 238,000 psi.

B. Bent-beam specimens of Ladish, 300M, PH 15-7 Mo, AM 355 steels, and the B120VCA titanium alloys are not susceptible to cracking in the environments tested for short-term exposure at ambient temperature.

C. Stressed U-bend specimens of Vascojet 1000, 300M, and Ladish steels are susceptible to stress-corrosion cracking in distilled water, tap water (with the exception of the Ladish alloy), and a 3% solution of sodium chloride. The threshold strength levels for these alloys vary with the solution employed. The threshold strength levels for the Vascojet alloy are as follows: (1) distilled water, between 194,000 and 212,000 psi; (2) tap water, between 212,000 and 240,000 psi; and (3) 3% sodium chloride solution, between 196,000 and 212,000 psi. The 300M material, which ranked second in susceptibility to stress-corrosion cracking, has the following threshold strength levels: (1) distilled water, between 196,000 and 213,000 psi; (2) sodium chloride (3%), between 196,000 and 213,000 psi; and (3) tap water, between 213,000 and 233,000 psi. The threshold strength levels for the Ladish alloy are as follows: (1) distilled water, between 223,000 and 235,000 psi; (2) the sodium chloride solution, between 235,000 and 252,000 psi. No susceptibility to stress-corrosion cracking of this Ladish alloy was detected in tap water.

D. None of the six alloys tested are susceptible to stress-corrosion cracking in cosmoline, trichlorethylene, and a 0.25% water solution of sodium dichromate for short-time immersions at ambient temperature. It is possible, however, that cracking will occur at some of the higher strength and stress levels during prolonged exposure.

TABLE 1

ANALYSES OF ALLOYS, VENDOR AND AEROJET DETERMINED

Alloy	Heat No.	Analyzer or Authority	C	Si	Mn	S	P	Cr	V	Mo	Ni	Al	N	O	H	Fe
Vascojet	-	AGC Spec.	0.37-	0.80-	0.20-	0.010	0.010	4.75-	0.40-	1.20-	-	-	-	-	-	-
1000		34016	0.43	1.10	0.40	Max	Max	5.25	0.60	1.40						
	05228	Vendor	0.38	0.90	0.22	0.007	0.009	5.19	0.50	1.20	-	-	-	-	-	-
	05228	AGC	0.35	0.67	0.32	0.006	0.007	4.78	0.47	1.31	-	-	-	-	-	-
	05235	Vendor	0.40	0.97	0.23	0.009	0.010	4.95	0.52	1.24	-	-	-	-	-	-
	05235	AGC	0.42	0.90	0.30	0.015	0.015	5.25	0.43	1.39	-	-	-	-	-	-
300M	-	AGC Mat.	0.40-	1.45-	0.65-	0.010	0.010	0.70-	0.05	0.30-	1.65-					
		Spec.M263	0.44	1.80	0.95	Max.	Max.	0.95	Min.	0.45	2.00					
	22695	Vendor	0.43	1.62	0.79	0.004	0.007	0.83	0.07	0.35	1.67	-	-	-	-	-
	22695	AGC	0.43	1.56	0.74	0.006	0.006	0.88	0.07	0.33	1.86	-	-	-	-	-
Ladish	-	AGC Spec.	0.42-	0.15-	0.60-	0.01	0.01	0.90-	0.08	0.90-	0.40-	-	-	-	-	-
D6AC		34035	0.48	0.30	0.90	Max.	Max.	1.20	Max.	1.10	0.70					
	W-23217	Vendor	0.49	0.20	0.62	0.003	0.009	1.00	0.05	0.94	0.57	-	-	-	-	-
	W-23217	AGC	0.48	0.25	0.58	0.006	0.008	1.00	0.09	1.02	0.49	-	-	-	-	-
AM355	-	AMS Spec.	0.10-	0.50	0.50-	0.030	0.040	15.00-	-	2.50-	4.00-	-	0.07-	-	-	-
		5547A	0.15	Max.	1.25	Max.	Max.	16.00	-	3.25	5.00		0.13			
	38174	Vendor	0.14	0.29	0.72	0.018	0.018	15.60	-	2.71	4.30	-	0.11	-	-	-
	38174	AGC	0.11	0.40	0.92	0.025	0.035	15.00	-	2.80	4.59	-	-	-	-	-
PH 15-7	-	AMS Spec.	0.09	1.00	1.00	0.03	0.04	14.00	-	2.00-	6.50-	0.75-	-	-	-	-
Mo SS		5520A	Max.	Max.	Max.	Max.	Max.	16.00		3.00	7.75	1.50				
	880656	Vendor	0.08	0.26	0.54	0.008	0.014	15.05	-	2.16	7.12	1.16	-	-	-	-
	880656	AGC	0.09	0.28	0.60	0.006	0.012	15.00	-	2.20	7.70	0.84	-	-	-	-
B120VCA	-	AGC Spec.	0.10	-	-	-	-	10.00-	12.50-	-	-	2.00-	0.05	0.20	0.175	0.30
Titanium		34010	Max.					12.00	15.50			4.00	Max.	Max.	Max.	Max.
		Vendor	0.02	-	-	-	-	11.20	13.70	-	-	3.00	0.02	-	0.0176	0.23
		AGC	0.02	-	-	-	-	14.56	12.38	-	-	3.41	0.030	0.129	0.0001	0.31

TABLE 2

LIST AND SOURCE OF ENVIRONMENTAL CHEMICALS

Material	Source
Distilled water	Deep Rock Water Co. Los Angeles, Calif.
Tap water	City of Azusa Light & Water Dept. Azusa, Calif.
Sodium dichromate	Braun Chemical Co. Los Angeles, California
Cosmoline	E. F. Houghton & Co. San Francisco, Calif.
Marquench salts	Far-Best Corp. Los Angeles, Calif.
Trichloroethylene	Detrex Chemical Industries, Inc. Detroit, Michigan
Soluble oil	Standard Oil Co. San Francisco, Calif.

TABLE 3

WATER-SAMPLE ANALYSES

Constituents	Formula	Tap Water	Distilled Water
Silica	SiO_2	18.4 ppm	*
Aluminum oxide	Al_2O_3	Trace	*
Iron oxide	Fe_2O_3	Trace	*
Calcium	Ca	66.9 ppm	None
Magnesium	Mg	11.2 ppm	*
Sodium	Na	17.9 ppm	*
Sulfate	SO_4	20.6 ppm	None
Chloride	Cl	15.0 ppm	None
Carbonate	CO_3	None	*
Bicarbonate	HCO_3	238.0 ppm	*
Nitrate	NO_3	19.0 ppm	*
Calcium bicarbonate	$Ca(HCO_3)_2$	271.0 ppm	*
Calcium sulfate	$CaSO_4$	None	*
Calcium chloride	$CaCl_2$	None	*
Magnesium bicarbonate	$Mg(HCO_3)_2$	41.0 ppm	*
Magnesium sulfate	$MgSO_4$	22.3 ppm	*
Magnesium chloride	$MgCl_2$	None	*
Sodium bicarbonate	$NaHCO_3$	None	*
Sodium carbonate	$NaCO_3$	None	*
Sodium sulfate	Na_2SO_4	4.3 ppm	*
Sodium chloride	NaCl	24.5 ppm	*
Sodium nitrate	$NaNO_3$	25.5 ppm	*
Total hardness	$CaCO_3$	214.0 ppm	*
Total solids	-	407.0 ppm	5 ppm
Total non-volatile solids	-	286.0 ppm	*
Specific conductance	(micromhos/cm)	438.5	*
Hydrogen ion concentration	(PH)	7.2	*
True color	-	10	None
Odor quality	-	None	None
Ammonia	NH_3	*	None
Turbidity	-	None	*
Suspended residue	-	None	*
Fluoride	F	0.2 ppm	*
Heavy metals	-	*	None
Oxidizable substances	-	*	None
Carbon dioxide	CO_2	*	None

*Not determined.

TABLE 4

MECHANICAL PROPERTIES OF LADISH D6AC TEST SPECIMENS*

Tempering Temperature, °F 2 hr	Yield Strength 0.2% Offset psi x 10^{-3}	Tensile Strength psi x 10^{-3}	Elongation (%) in 2 in.	Hardness, Rockwell C
600	249.1	280.1	5.0	52.0
	252.3	282.1	5.0	51.0
	253.9	281.1	5.0	52.5
800	234.4	254.5	5.0	51.0
	235.0	254.5	5.0	50.0
	235.6	254.5	5.5	50.0
900	219.5	231.8	6.0	48.0
	222.3	234.7	6.0	47.0
	226.3	239.7	7.0	48.0
1100	190.6	201.9	9.0	44.0
	200.6	211.2	7.5	45.0
	201.6	211.8	8.0	45.0

*Normalized at 1650°F for 1 hr; air-cooled, austenitized at 1550°F for 40 min; oil-quenched and tempered at the temperatures indicated.

TABLE 5

MECHANICAL PROPERTIES OF TYPE 300M TEST SPECIMENS*

Tempering Temperature, °F 2 hr	Yield Strength 0.2% Offset psi x 10^{-3}	Tensile Strength psi x 10^{-3}	Elongation (%) in 2 in.	Hardness, Rockwell C
550 600	232.3	279.6	6.0	51.5
	232.6	278.2	6.5	51.5
	234.3	281.2	6.0	51.5
700 750	208.8	247.0	7.0	49.0
	214.1	255.3	7.0	50.5
	216.5	257.0	7.0	47.5
750 800	195.2	242.1	7.0	47.5
	195.7	239.9	7.5	47.0
	196.4	240.3	7.5	46.5

*Normalized at 1675°F for 1 hr; air-cooled, austenitized at 1650°F for 15 min; oil-quenched and tempered at the conditions indicated.

TABLE 6

MECHANICAL PROPERTIES OF VASCOJET 1000 TEST SPECIMENS*

Tempering Temperature, °F 4 + 4 hr	Yield Strength 0.2% Offset psi x 10^{-3}	Tensile Strength psi x 10^{-3}	Elongation (%) in 2 in.	Hardness, Rockwell C
940	236.9	305.7	7.0	55.0
	238.9	305.6	7.0	55.5
	244.2	310.3	7.0	55.5
975	232.0	295.6	6.0	54.0
	240.6	300.9	7.0	55.0
	240.6	301.9	7.0	54.5
1025	211.6	254.9	8.0	50.0
	211.9	254.2	7.5	50.0
	212.2	255.2	8.5	50.5
1075	189.8	227.6	8.5	45.0
	193.7	232.8	8.5	47.5
	198.4	238.2	8.5	47.5

*Austenitized at 1850°F for 1 hr; air-quenched and tempered at the temperatures indicated.

TABLE 7

MECHANICAL PROPERTIES OF AM355 STAINLESS STEEL TEST SPECIMENS*

Evaluator	Testing Direction	Thickness in.	Yield Strength 0.2% Offset psi x 10^{-3}	Tensile Strength psi x 10^{-3}	Elongation (%) in 2 in.	Hardness, Rockwell C
Aerojet	Longitudinal	0.038	245.7	263.0	16.0	53.0
Aerojet	Transverse	0.038	199.1	266.5	13.2	53.2
Wallingford	Longitudinal	0.038	250.6	258.9	14.0	**
Wallingford	Transverse	0.038	210.0	275.5	11.0	52.0
Mellon	Longitudinal	0.038	250.0	261.0	14.5	**
Aerojet	Longitudinal	0.036	249.8	265.8	14.2	54.2
Wallingford	Longitudinal	0.036	259.7	264.4	14.0	**
Wallingford	Transverse	0.036	226.5	275.5	11.0	52.0
Mellon	Longitudinal	0.036	275.0	265.0	15.3	**
Aerojet	Longitudinal	0.033	278.4	295.1	4.0	55.5
Wallingford	Longitudinal	0.033	298.0	303.0	3.5	**
Wallingford	Transverse	0.033	251.5	296.0	7.5	54.0
Mellon	Longitudinal	0.033	302.0	311.0	3.8	**

* Cold-rolled to the various strength levels.
** Not reported.

TABLE 8

MECHANICAL PROPERTIES OF PH 15-7 Mo STAINLESS STEEL TEST SPECIMENS*

Tempering Temperature, °F 1 hr	Yield Strength 0.2% Offset psi x 10^{-3}	Tensile Strength psi x 10^{-3}	Elongation (%) in 2 in.	Hardness, Rockwell C
None	199.4	233.1	3.5	45.5
	199.4	233.8	4.0	45.5
	199.7	233.1	3.5	45.5
1080	222.6	234.2	4.5	46.5
	226.6	239.6	4.5	46.5
	226.6	239.6	4.5	47.0
1050	236.4	247.4	4.0	48.5
	236.4	248.1	3.5	49.0
	238.6	251.9	3.5	48.5

*Received in cold-rolled condition.

TABLE 9

MECHANICAL PROPERTIES OF B120VCA TITANIUM TEST SPECIMENS*

Aging Time hr	Testing Direction	Yield Strength 0.2% Offset psi x 10^{-3}	Tensile Strength psi x 10^{-3}	Elongation (%) in 2 in.	Hardness, Rockwell C
12	Longitudinal	137.1	138.9	15.5	29.5
		137.6	140.0	14.0	29.5
		137.9	140.0	13.0	29.5
12	Transverse	139.1	141.7	12.5	29.5
		140.0	141.8	13.0	30.5
45	Longitudinal	146.5	160.6	10.0	33.5
		149.4	166.5	8.0	34.5
		151.8	167.0	8.0	35.5
32	Transverse	144.5	154.9	11.0	32.5
		146.7	156.4	12.0	32.5
75	Longitudinal	156.1	176.2	8.0	37.5
		158.1	174.9	6.0	37.5
		159.1	181.3	8.5	38.5
75	Transverse	166.0	186.4	6.0	38.5
		166.2	187.1	6.0	39.0

*Aged in air at 900°F for the times indicated.

TABLE 10

STRAIN-GAGE EVALUATIONS*

Yield Strength 0.2% Offset psi x 10^{-3}	Maximum Tensile Strain, in. x 10^{6} Strain-Gage Reading	Maximum Tensile Stress, psi x 10^{-3} Calculated from Strain-Gage Readings	Maximum Tensile Stress, psi x 10^{-3} Calculated from Tables
194.0	7270	218.1	145.5
194.0	6360	190.8	145.5
212.0	6630	198.9	159.0
212.0	5770	173.1	159.0
238.0	7325	219.8	178.3
238.0	7330	219.9	178.3
242.0	8100	243.0	181.8
242.0	7490	224.7	181.8

*Tatnall C6-141 foil-type strain gages used on Vascojet 1000 specimens.

TABLE 11

BENT-BEAM STRESS-CORROSION TEST DATA, AIR*

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	No. of Specimens	Time to Failure (Days)	Total Testing Time (Days)
Ladish	198.0	3	NF**	28
	223.0	3	NF	28
	235.0	3	NF	28
	252.0	3	NF	28
Type 300M	196.0	3	NF	28
	213.0	3	NF	28
	233.0	3	NF	28
Vascojet 1000	194.0	3	NF	28
	212.0	3	NF	28
	238.0	3	NF	28
	242.0	3	NF	28
AM355	199.0(T)***	3	NF	28
	250.0(L)	3	NF	28
	278.0(L)	3	NF	28
B120VCA Titanium	138.0(L)	3	NF	28
	140.0(T)	3	NF	28
	146.0(T)	3	NF	28
	149.0(L)	3	NF	28
	158.0(L)	3	NF	28
	166.0(T)	3	NF	28

* Stressed at 75% of the yield strength.
** No failure.
*** L = longitudinal, T = transverse.

TABLE 12

BENT-BEAM STRESS-CORROSION TEST DATA, DISTILLED WATER*

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	No. of Specimens	Time to Failure (Days)	Total Testing Time (Days)
Ladish D6AC	198.0	3	NF**	21
	223.0	3	NF	21
	235.0	3	NF	21
	252.0	3	NF	21
Type 300M	196.0	3	NF	21
	213.0	3	NF	21
	233.0	3	NF	21
Vascojet 1000	194.0	3	NF	21
	212.0	3	NF	21
	238.0	1	7.6	--
	238.0	1	7.8	--
	238.0	1	8.9	--
	242.0	1	1.8	--
	242.0	1	3.2	--
	242.0	1	4.3	--
AM355	199.0(T)***	3	NF	21
	250.0(L)	3	NF	21
	278.0(L)	3	NF	21
B120VCA Titanium	138.0(L)	3	NF	21
	140.0(T)	3	NF	21
	146.0(T)	3	NF	21
	149.0(T)	3	NF	21
	158.0(L)	3	NF	21
	166.0(T)	3	NF	21

* Stressed at 75% of the yield strength.
** No failure.
*** L = longitudinal, T = transverse.

TABLE 13

U-BEND STRESS-CORROSION TEST DATA, DISTILLED WATER

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	No. of Specimens	Time to Failure (Days)	Total Testing Time (Days)
Ladish D6AC	198.0	2	NF*	27
	223.0	2	NF	27
	235.0	1	20.2	--
	252.0	1	18.4	--
	252.0	1	22.4	--
Type 300M	196.0	2	NF	27
	213.0	1	NF	27
	213.0	1	18.4	--
	233.0	1	NF	27
	233.0	1	14.4	--
Vascojet 1000	194.0	2	NF	27
	212.0	1	NF	27
	212.0	1	14.7	--
	240.0	1	4.4	--
	240.0	1	11.4	--

*No failure.

TABLE 14

BENT-BEAM STRESS-CORROSION TEST DATA, TAP WATER*

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	No. of Specimens	Time to Failure (Days)	Total Testing Time (days)
Ladish D6AC	198.0	3	NF**	21
	223.0	3	NF	21
	235.0	3	NF	21
	252.0	3	NF	21
Type 300M	196.0	3	NF	21
	213.0	3	NF	21
	233.0	3	NF	21
Vascojet 1000	194.0	3	NF	21
	212.0	1	NF	21
	238.0	1	13.7	--
	238.0	1	14.7	--
	238.0	1	15.7	--
	242.0	1	2.7	--
	242.0	1	8.8	--
	242.0	1	9.7	--
AM355	199.0(T)***	3	NF	21
	250.0(L)	3	NF	21
	278.0(L)	3	NF	21
B120VCA Titanium	138.0(L)	3	NF	21
	140.0(T)	3	NF	21
	146.0(T)	3	NF	21
	149.0(L)	3	NF	21
	158.0(L)	3	NF	21
	166.0(T)	3	NF	21

* Stressed at 75% of the yield strength.
** No failure.
*** L = longitudinal, T = transverse.

TABLE 15

U-BEND STRESS-CORROSION TEST DATA, TAP WATER

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	No. of Specimens	Time to Failure (Days)	Total Testing Time (Days)
Ladish D6AC	198.0	2	NF*	27
	223.0	2	NF	27
	235.0	2	NF	27
	252.0	2	NF	27
Type 300M	196.0	2	NF	27
	213.0	2	NF	27
	233.0	1	NF	27
	233.0	1	22.4	-
Vascojet 1000	194.0	2	NF	27
	212.0	2	NF	27
	240.0	1	7.4	-
	240.0	1	19.5	-

*No failure.

TABLE 16

BENT-BEAM STRESS-CORROSION TEST DATA, 0.25% SODIUM DICHROMATE SOLUTION*

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	No. of Specimens	Time to Failure(Days)	Total Testing Time (Days)
Ladish D6AC	198.0	3	NF**	21
	233.0	3	NF	21
	235.0	3	NF	21
	252.0	3	NF	21
Type 300M	196.0	3	NF	21
	213.0	3	NF	21
	233.0	3	NF	21
Vascojet 1000	194.0	3	NF	21
	212.0	3	NF	21
	238.0	3	NF	21
	242.0	3	NF	21
AM355	199.0(T)***	3	NF	21
	250.0(L)	3	NF	21
	278.0(L)	3	NF	21
B120VCA Titanium	138.0(L)	3	NF	21
	140.0(T)	3	NF	21
	146.0(T)	3	NF	21
	149.0(L)	3	NF	21
	158.0(L)	3	NF	21
	166.0(T)	3	NF	21

*Stressed at 75% of the yield strength.
**No failure.
***L = longitudinal, T = transverse.

TABLE 17

U-BEND STRESS-CORROSION TEST DATA, 0.25% SODIUM DICHROMATE SOLUTION

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	No. of Specimens	Time to Failure(Days)	Total Testing Time (Days)
Ladish D6AC	198.0	2	NF*	27
	223.0	2	NF	27
	235.0	1	NF	27
	252.0	2	NF	27
Type 300M	196.0	2	NF	27
	213.0	2	NF	27
	233.0	2	NF	27
Vascojet 1000	194.0	2	NF	27
	212.0	2	NF	27
	240.0	2	NF	27

*No failure.

TABLE 18

BENT-BEAM STRESS-CORROSION TEST DATA, 1% MARQUENCH SALT SOLUTION*

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	No. of Specimens	Time to Failure(Days)	Total Testing Time (Days)
Ladish D6AC	198.0	3	NF**	21
	223.0	3	NF	21
	235.0	3	NF	21
	252.0	3	NF	21
Type 300M	196.0	3	NF	21
	213.0	3	NF	21
	233.0	3	NF	21
Vascojet 1000	194.0	3	NF	21
	212.0	3	NF	21
	238.0	3	NF	21
	242.0	3	NF	21
AM355	199.0(T)***	3	NF	21
	250.0(L)	3	NF	21
	278.0(L)	3	NF	21
B120VCA Titanium	138.0(L)	3	NF	21
	140.0(T)	3	NF	21
	146.0(T)	3	NF	21
	149.0(L)	3	NF	21
	158.0(L)	3	NF	21
	166.0(T)	3	NF	21

*Stressed at 75% of the yield strength.
**No failure.
***L = longitudinal, T = transverse.

TABLE 19

U-BEND STRESS-CORROSION TEST DATA, 1% MARQUENCH SALT SOLUTION

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	No. of Specimens	Time to Failure(Days)	Total Testing Time (Days)
Ladish D6AC	198.0	2	NF*	27
	223.0	2	NF	27
	235.0	2	NF	27
	252.0	1	NF	27
Type 300M	196.0	2	NF	27
	213.0	2	NF	27
	233.0	2	NF	27
Vascojet 1000	194.0	2	NF	27
	212.0	2	NF	27
	240.0	2	NF	27

*No failure.

TABLE 20

BENT-BEAM STRESS-CORROSION TEST DATA, 3% SODIUM CHLORIDE SOLUTION*

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	No. of Specimens	Time to Failure(Days)	Total Testing Time (Days)
Ladish D6AC	198.0	3	NF**	21
	223.0	3	NF	21
	235.0	3	NF	21
	252.0	3	NF	21
Type 300M	196.0	3	NF	21
	213.0	3	NF	21
	233.0	3	NF	21
Vascojet 1000	194.0	3	NF	21
	212.0	3	NF	21
	238.0	1	6.9	-
	238.0	1	10.0	-
	238.0	1	10.1	-
	242.0	1	1.2	-
	242.0	1	1.7	-
	242.0	1	6.7	-
AM355	199.0(T)***	3	NF	21
	250.0(L)	3	NF	21
	278.0(L)	3	NF	21
B120VCA Titanium	138.0(L)	3	NF	21
	140.0(T)	1	NF	21
	140.0(T)	1	0.00	-
	140.0(T)	1	0.03	-
	146.0(T)	3	NF	21
	149.0(L)	3	NF	21
	158.0(L)	3	NF	21
	166.0(T)	3	NF	21

*Stressed at 75% of yield strength.
**No failure.
***L = longitudinal, T = transverse.

TABLE 21

U-BEND STRESS-CORROSION TEST DATA, 3% SODIUM CHLORIDE SOLUTION

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	No. of Specimens	Time to Failure (Days)	Total Testing Time (Days)
Ladish D6AC	198.0	2	NF*	27
	223.0	2	NF	27
	235.0	2	NF	27
	252.0	1	18.5	-
Type 300M	196.0	2	NF	27
	213.0	1	NF	27
	213.0	1	11.3	-
	233.0	1	11.3	-
	233.0	1	26.3	-
Vascojet 1000	194.0	2	NF	27
	212.0	1	NF	27
	212.0	1	13.7	-
	240.0	1	4.3	-
	240.0	1	6.8	-

*No failure.

TABLE 22

BENT-BEAM STRESS-CORROSION TEST DATA, TRICHLOROETHYLENE*

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	No. of Specimens	Time to Failure (Days)	Total Testing Time (Days)
Ladish D6AC	198.0	3	NF**	21
	223.0	3	NF	21
	235.0	3	NF	21
	252.0	3	NF	21
Type 300M	196.0	3	NF	21
	213.0	3	NF	21
	233.0	3	NF	21
Vascojet 1000	194.0	3	NF	21
	212.0	3	NF	21
	238.0	3	NF	21
	242.0	3	NF	21
AM355	199.0(T)	3	NF	21
	250.0(L)	3	NF	21
	278.0(L)	3	NF	21
B120VCA Titanium	138.0(L)	3	NF	21
	140.0(T)	2	NF	21
	140.0(T)	1	3.4	-
	146.0(T)	2	NF	21
	146.0(T)	1	0.9	-
	149.0(L)	3	NF	21
	158.0(L)	3	NF	21
	166.0(T)	3	NF	21

* Stressed at 75% of the yield strength.
** No failure.
*** L = longitudinal, T = transverse.

TABLE 23

U-BEND STRESS-CORROSION TEST DATA, TRICHLOROETHYLENE

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	No. of Specimens	Time to Failure(Days)	Total Testing Time (Days)
Ladish D6AC	198.0	2	NF*	27
	223.0	2	NF	27
	235.0	2	NF	27
	252.0	2	NF	27
Type 300M	196.0	2	NF	27
	213.0	2	NF	27
	233.0	2	NF	27
Vascojet 1000	194.0	2	NF	27
	212.0	2	NF	27
	240.0	2	NF	27

*No failure.

TABLE 24

BENT-BEAM STRESS-CORROSION TEST DATA, COSMOLINE*

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	No. of Specimens	Time to Failure(Days)	Total Testing Time (Days)
Ladish D6AC	198.0	3	NF**	21
	223.0	3	NF	21
	235.0	3	NF	21
	252.0	3	NF	21
Type 300M	196.0	3	NF	21
	213.0	3	NF	21
	233.0	3	NF	21
Vascojet 1000	194.0	3	NF	21
	212.0	3	NF	21
	238.0	3	NF	21
	242.0	3	NF	21
	199.0(T)***	3	NF	21
	250.0(L)	3	NF	21
	278.0(L)	3	NF	21
B120VCA Titanium	138.0(L)	3	NF	21
	140.0(T)	3	NF	21
	146.0(T)	3	NF	21
	149.0(L)	3	NF	21
	158.0(L)	3	NF	21
	166.0(T)	3	NF	21

*Stressed to 75% of the yield strength.
**No failure.
***L = longitudinal, T = transverse.

TABLE 25

U-BEND STRESS-CORROSION TEST DATA, COSMOLINE

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	No. of Specimens	Time to Failure(Days)	Total Testing Time (Days)
Ladish D6AC	198.0	2	NF*	27
	223.0	2	NF	27
	235.0	2	NF	27
	252.0	2	NF	27
Type 300M	196.0	2	NF	27
	213.0	2	NF	27
	233.0	2	NF	27
Vascojet 1000	194.0	2	NF	27
	212.0	2	NF	27
	240.0	2	NF	27

*No failure.

TABLE 26

BENT-BEAM STRESS-CORROSION TEST DATA, 4% SOLUBLE OIL SOLUTION*

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	No. of Specimens	Time to Failure(Days)	Total Testing Time (Days)
Ladish D6AC	198.0	3	NF**	21
	223.0	3	NF	21
	235.0	3	NF	21
	252.0	3	NF	21
Type 300M	196.0	3	NF	21
	213.0	3	NF	21
	233.0	3	NF	21
Vascojet 1000	194.0	3	NF	21
	212.0	3	NF	21
	238.0	3	NF	21
	242.0	3	NF	21
AM355	199.0(T)***	3	NF	21
	250.0(L)	3	NF	21
	278.0(L)	3	NF	21
B120VCA Titanium	138.0(L)	3	NF	21
	140.0(T)	3	NF	21
	146.0(T)	3	NF	21
	149.0(L)	3	NF	21
	158.0(L)	3	NF	21
	166.0(T)	3	NF	21

*Stressed to 75% of the yield strength.
**No failure.
***L = longitudinal, T = transverse.

TABLE 27

U-BEND STRESS-CORROSION TEST DATA, 4% SOLUBLE OIL SOLUTION

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	No. of Specimen	Time to Failure(Days)	Total Testing Time (Days)
Ladish D6AC	198.0	2	NF*	27
	223.0	2	NF	27
	235.0	2	NF	27
	252.0	2	NF	27
Type 300M	196.0	2	NF	27
	213.0	2	NF	27
	233.0	2	NF	27
Vascojet 1000	194.0	2	NF	27
	212.0	2	NF	27
	240.0	2	NF	27

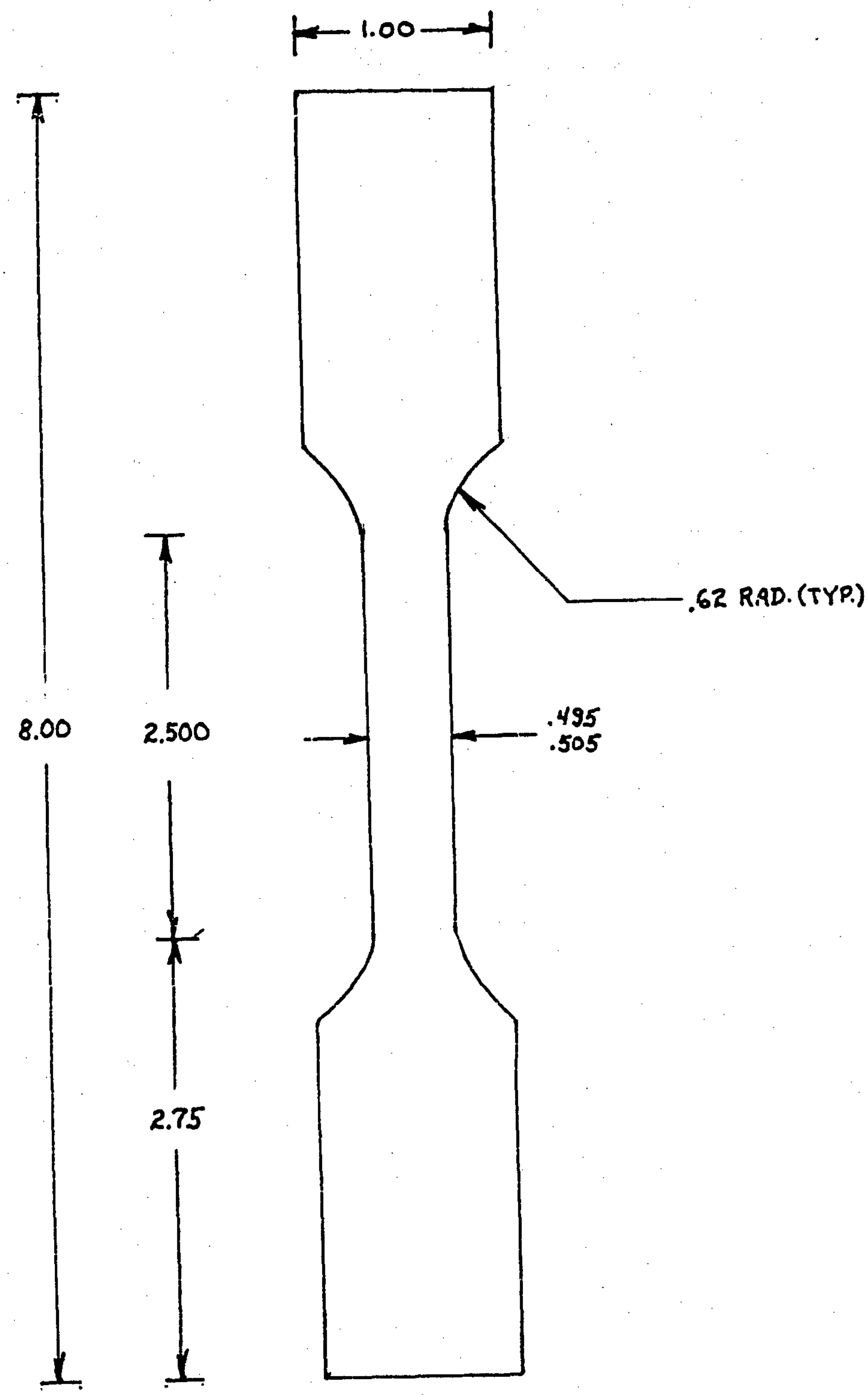
*No failure.

TABLE 28

BENT-BEAM STRESS-CORROSION TEST DATA, HIGH HUMIDITY*

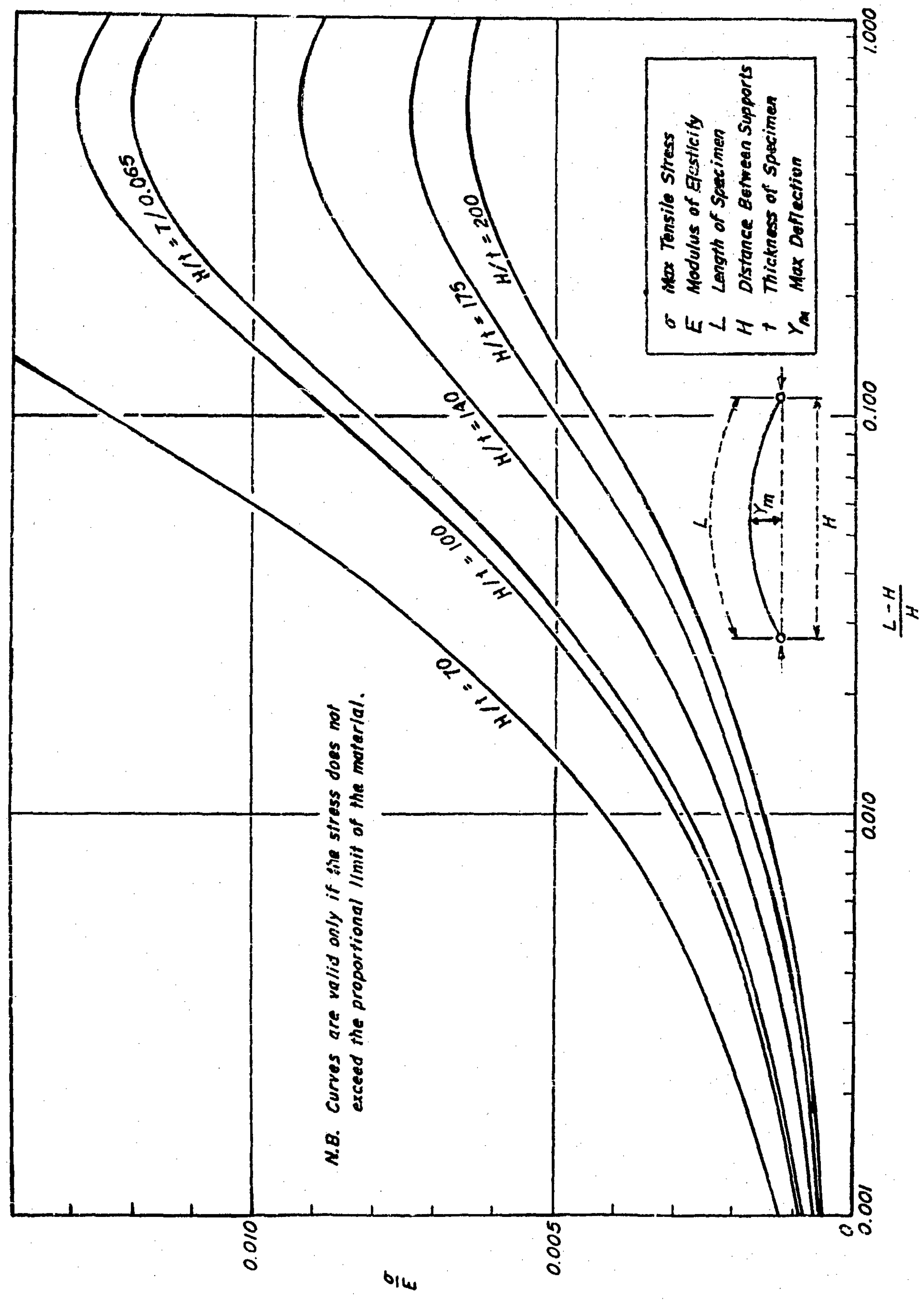
Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	No. of Specimens	Time to Failure(Days)	Total Testing Time (Days)
Ladish D6AC	198.0	3	NF**	45
	223.0	3	NF	45
	235.0	1	23.0	-
	235.0	1	23.2	-
	235.0	1	26.7	-
	252.0	1	5.7	-
	252.0	1	7.0	-
	252.0	1	14.2	-

*Stressed to 75% of the yield strength.
**No failure.



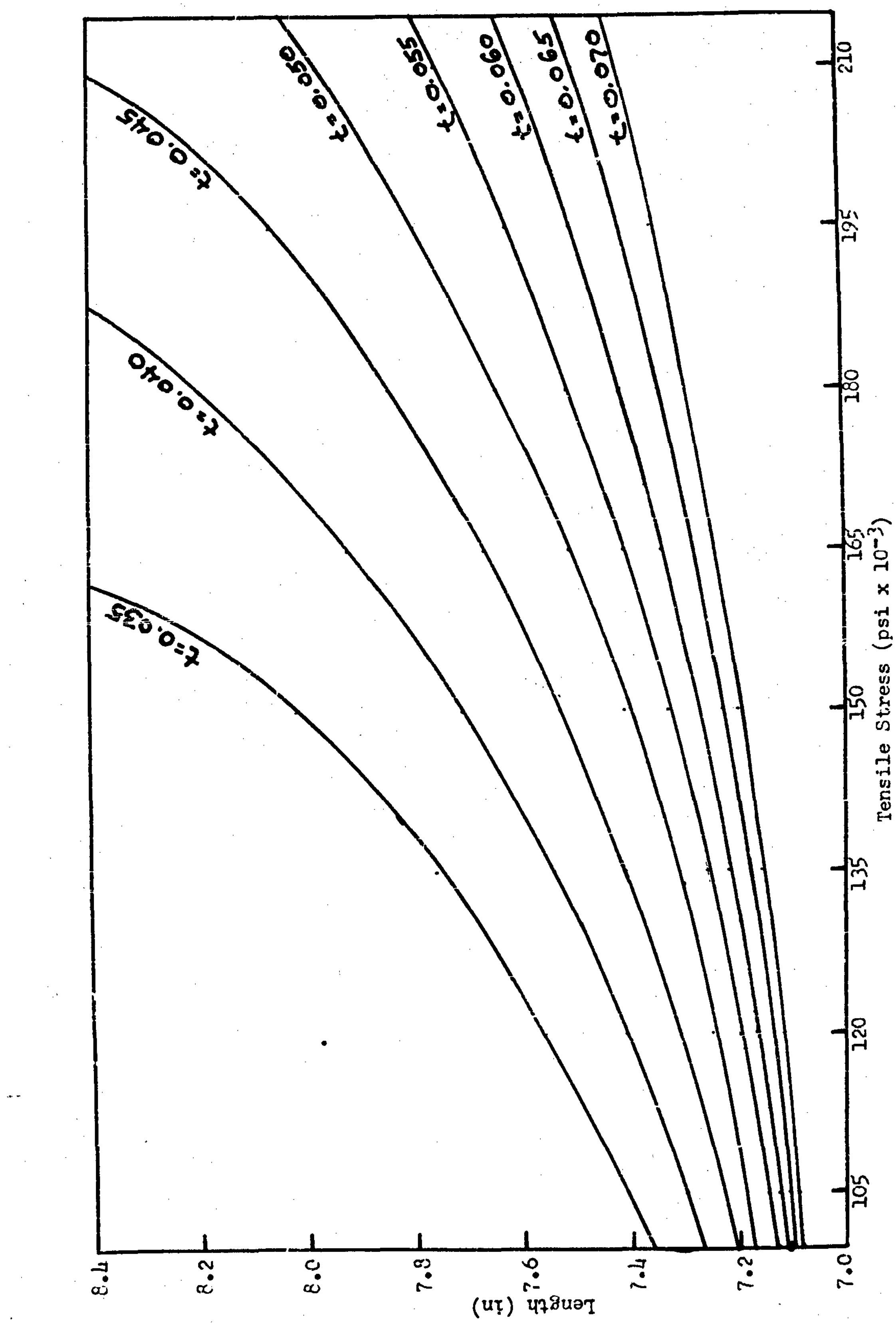
Tensile Specimen Diagram

Figure 1



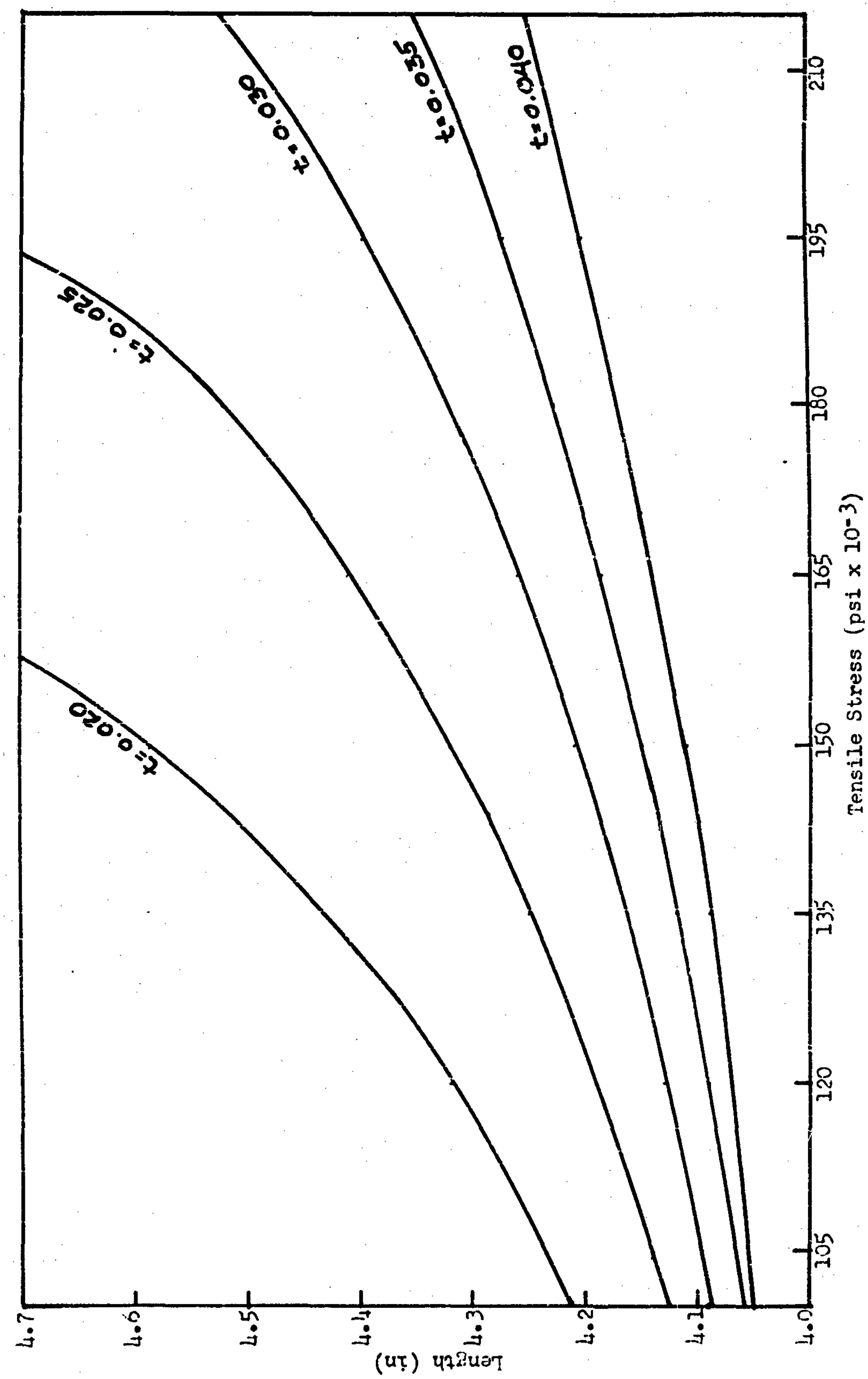
Tensile Stress in Strip Corrosion Specimen

Figure 2



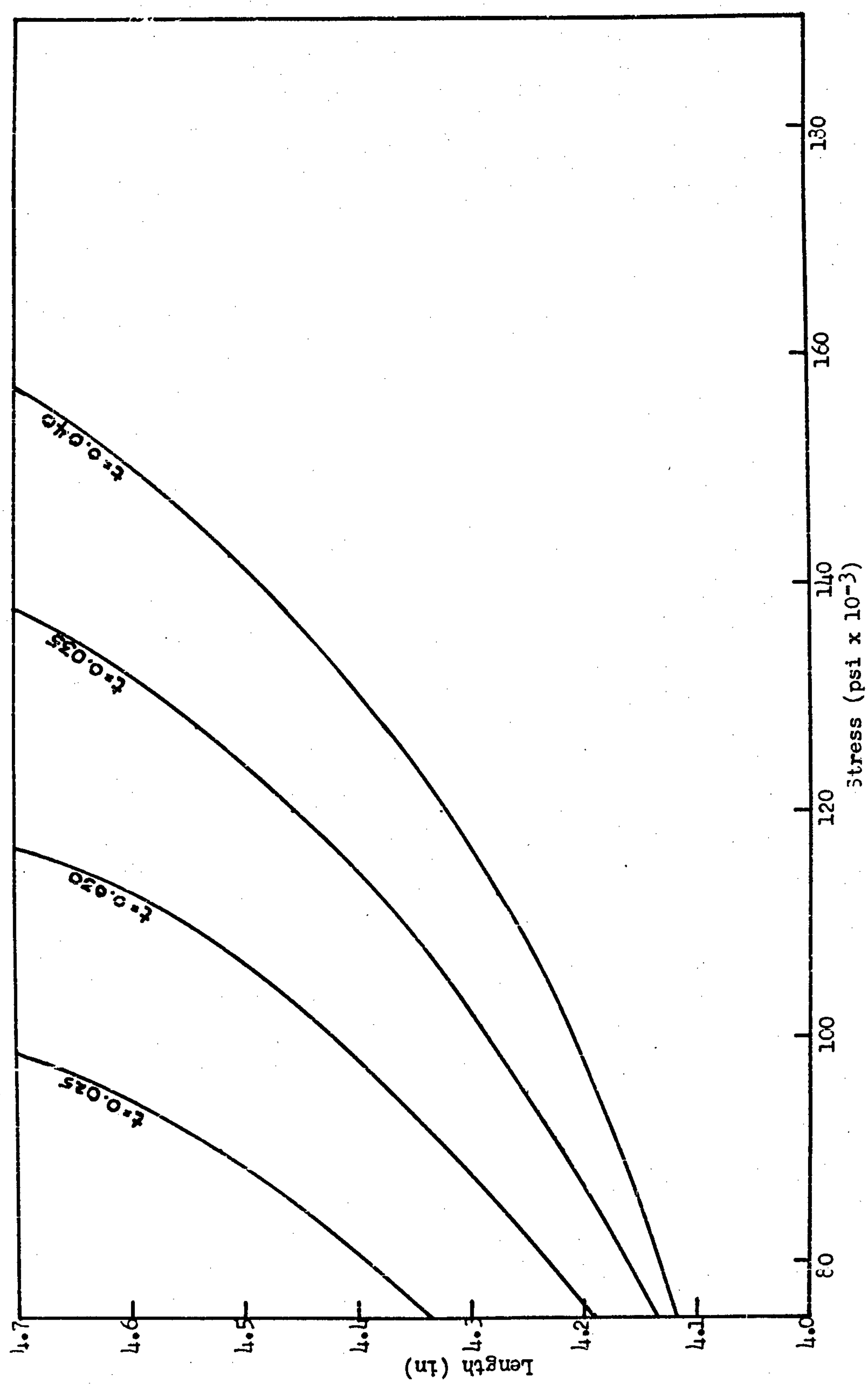
Tensile Stresses in Bent Beams for Steel Over a 7.00-inch Span

Figure 3



Tensile Stresses in Bent Beams for Steel Over a 4.00-inch Span

Figure 4

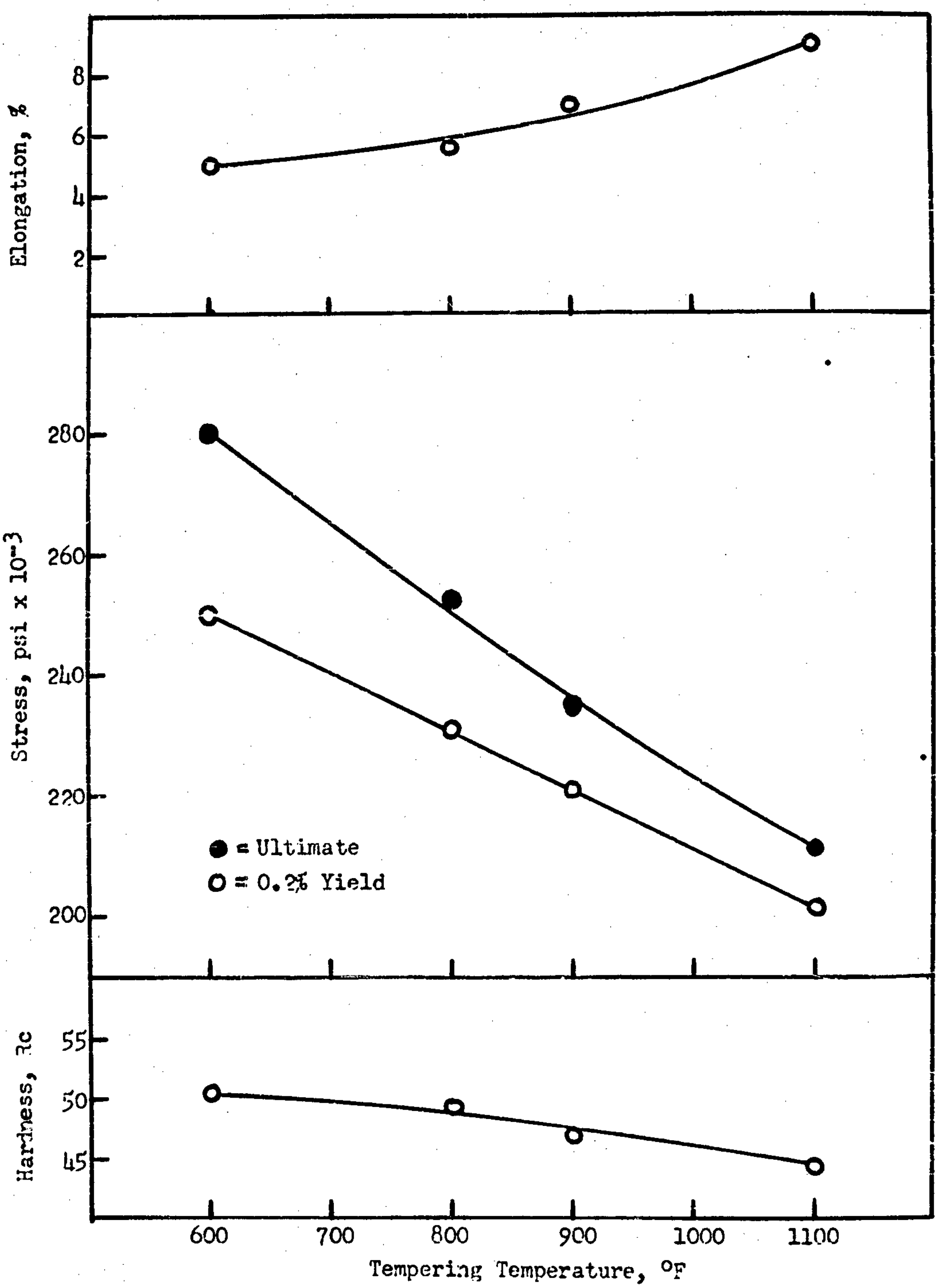


Tensile Stresses in Bent Beams for Titanium Over a 4.00-inch Span

Figure 5

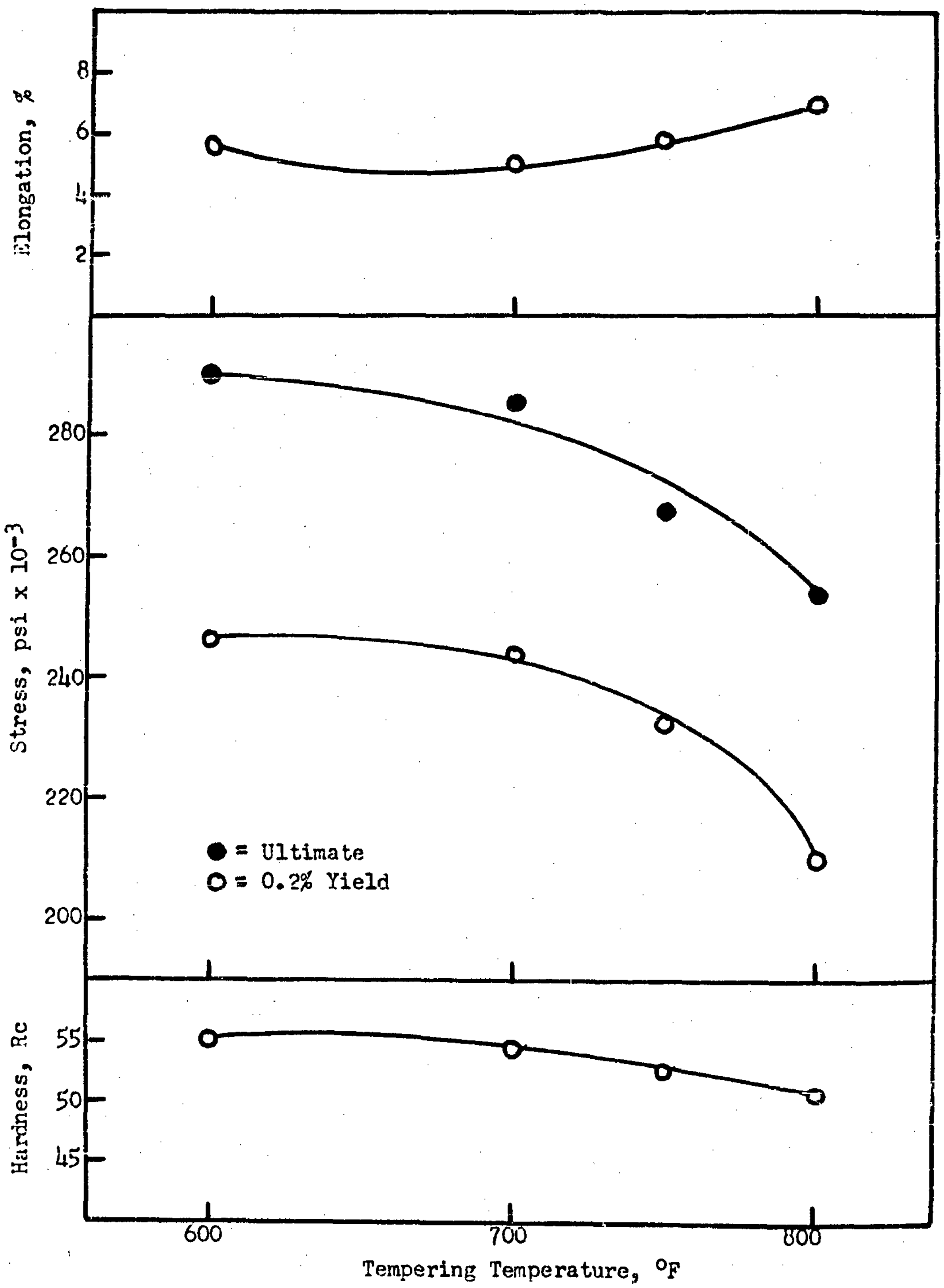
U-Bend Test Specimen

Figure 6



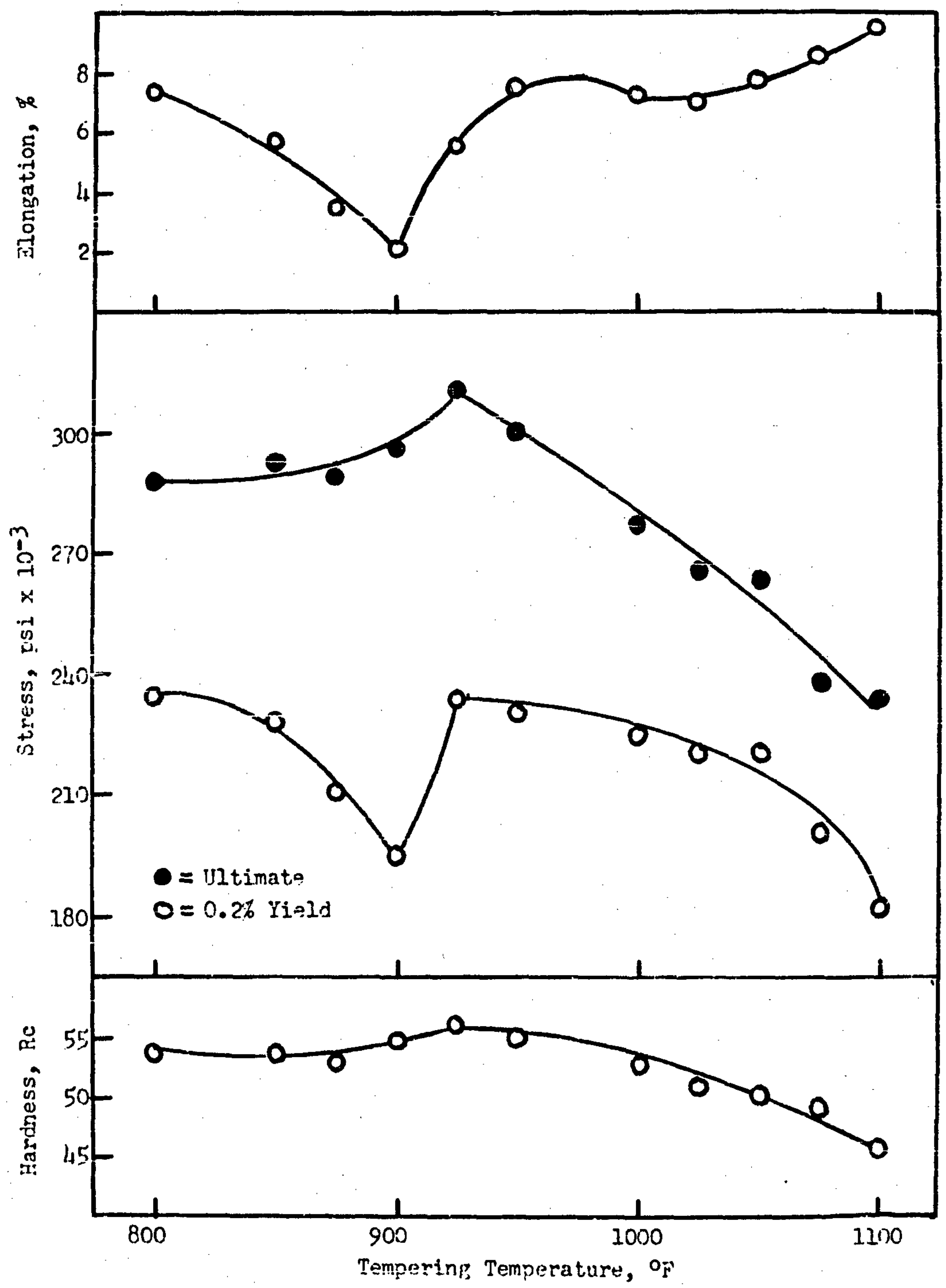
Mechanical Properties of Ladish D6AC Alloy Steel

Figure 7



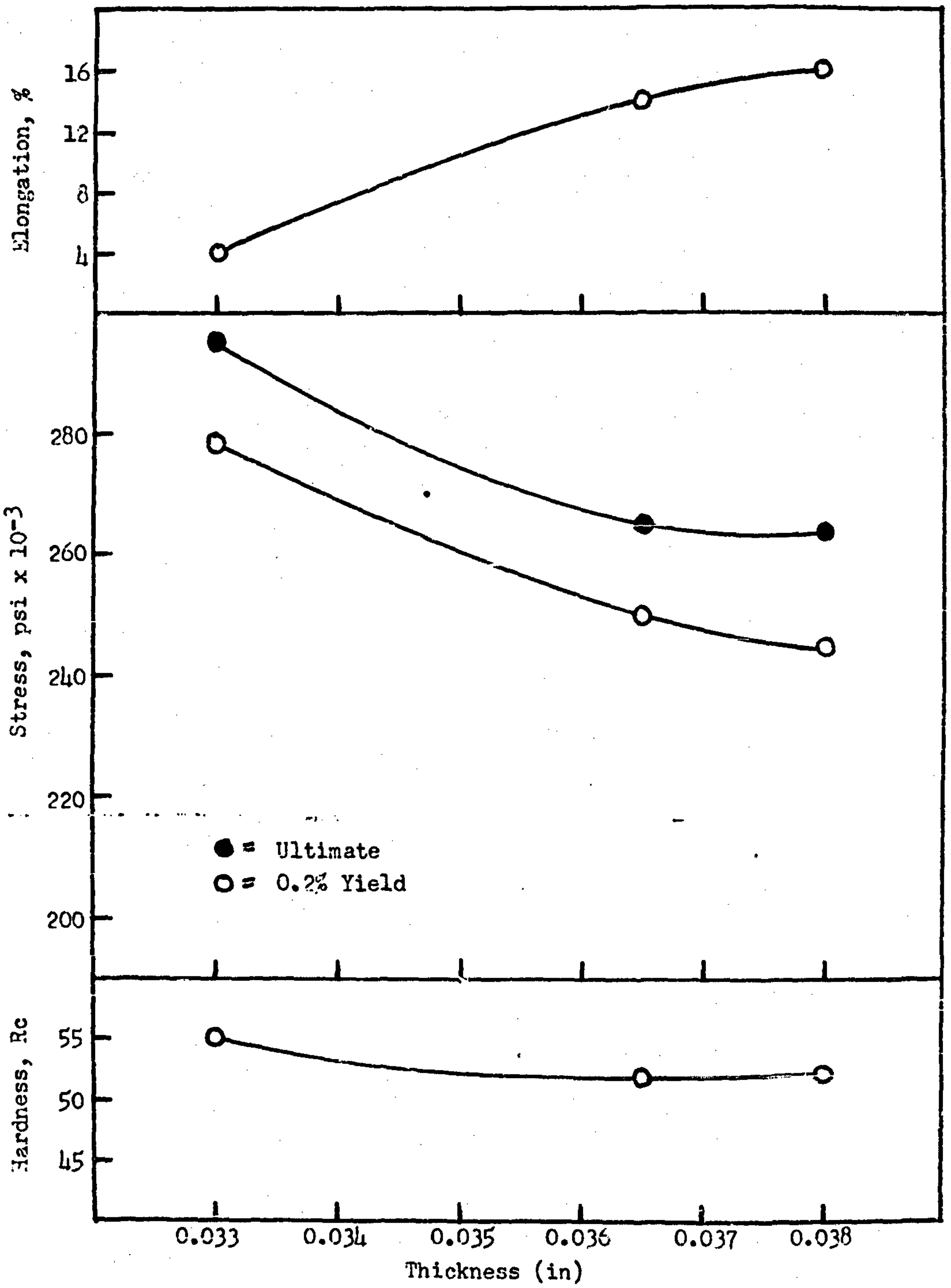
Mechanical Properties of Type 300M Alloy Steel

Figure 8



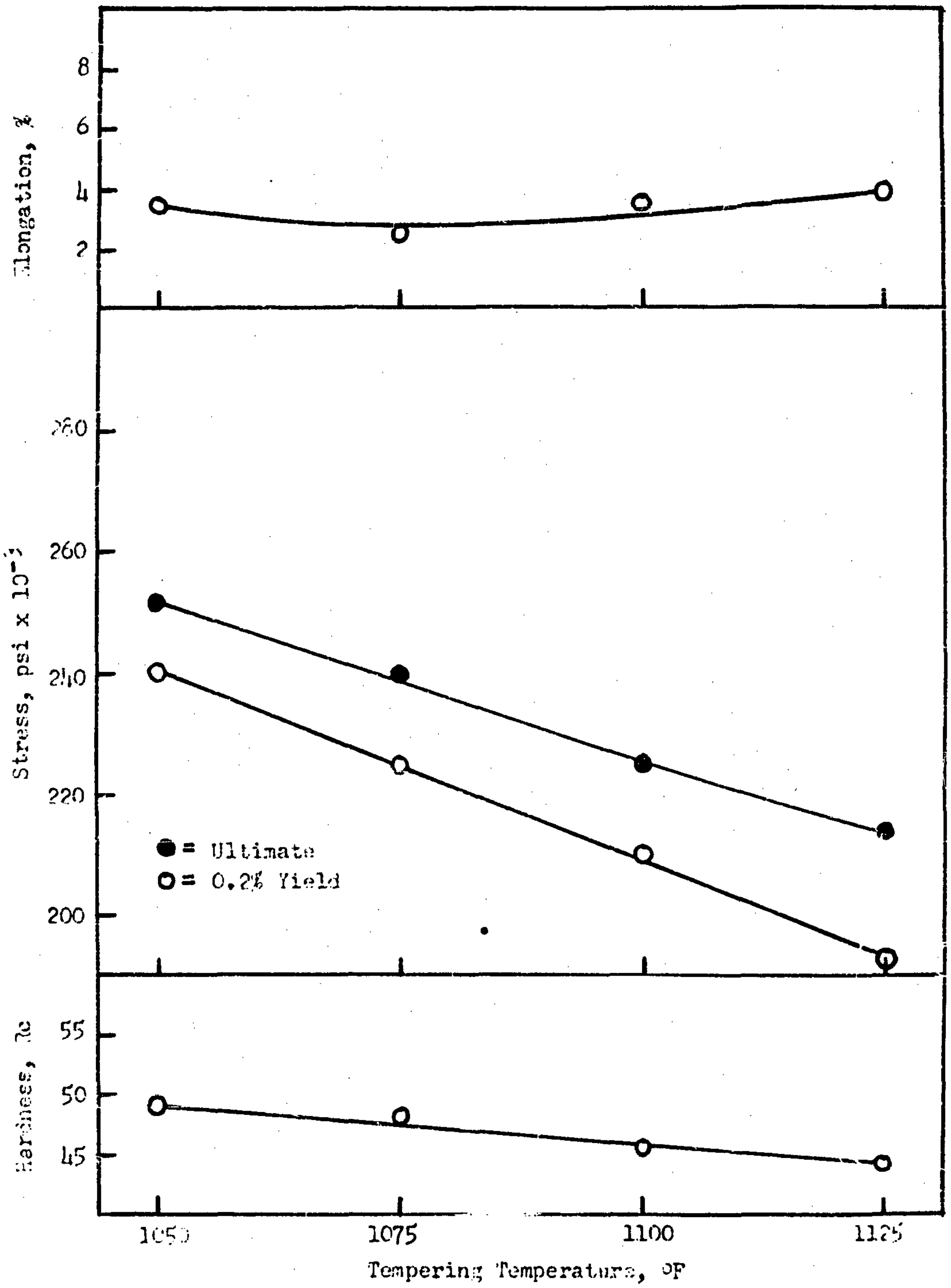
Mechanical Properties of Vascojet 1000 Alloy Steel

Figure 9



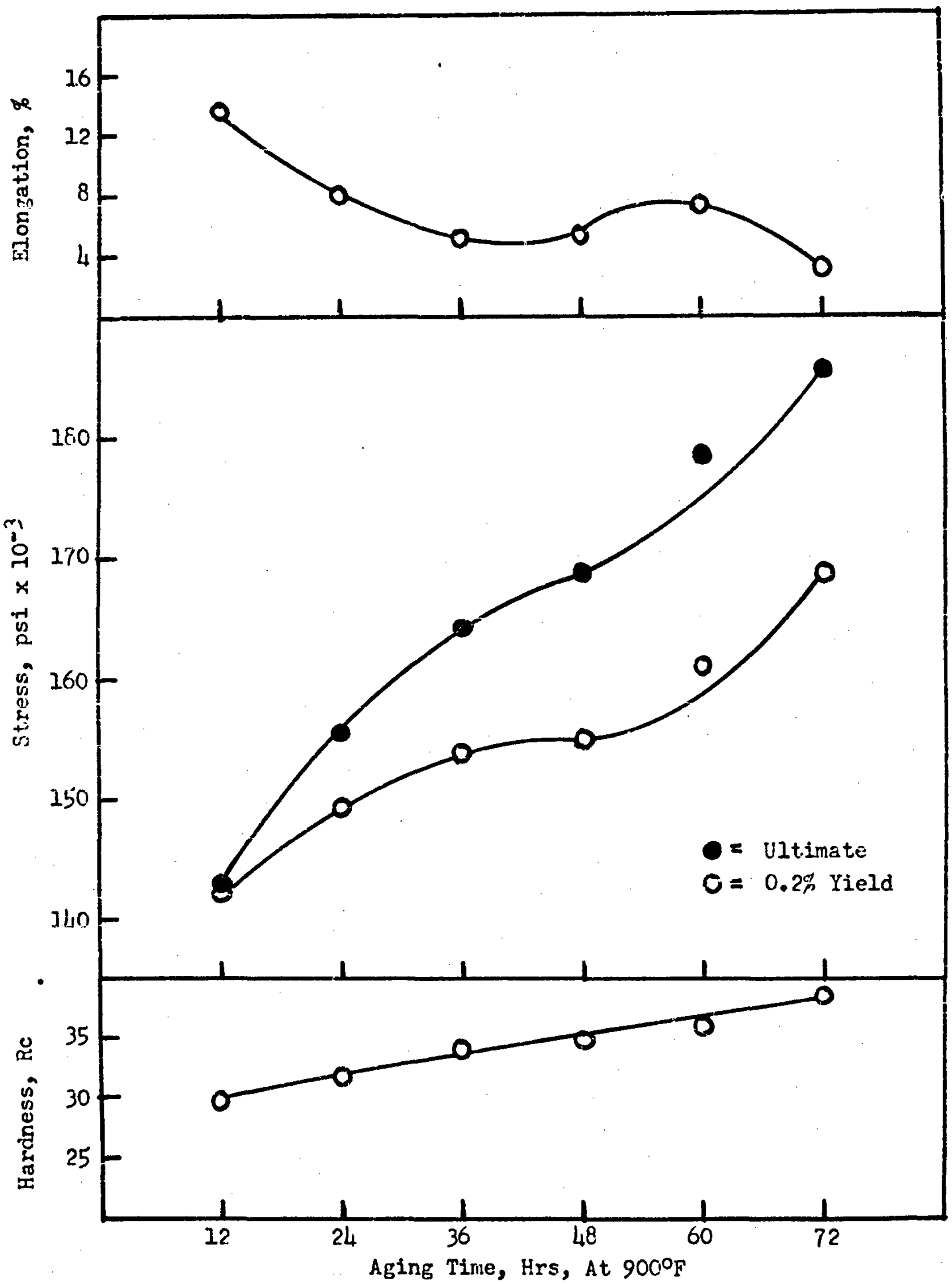
Mechanical Properties of AM355 Stainless Steel

Figure 10



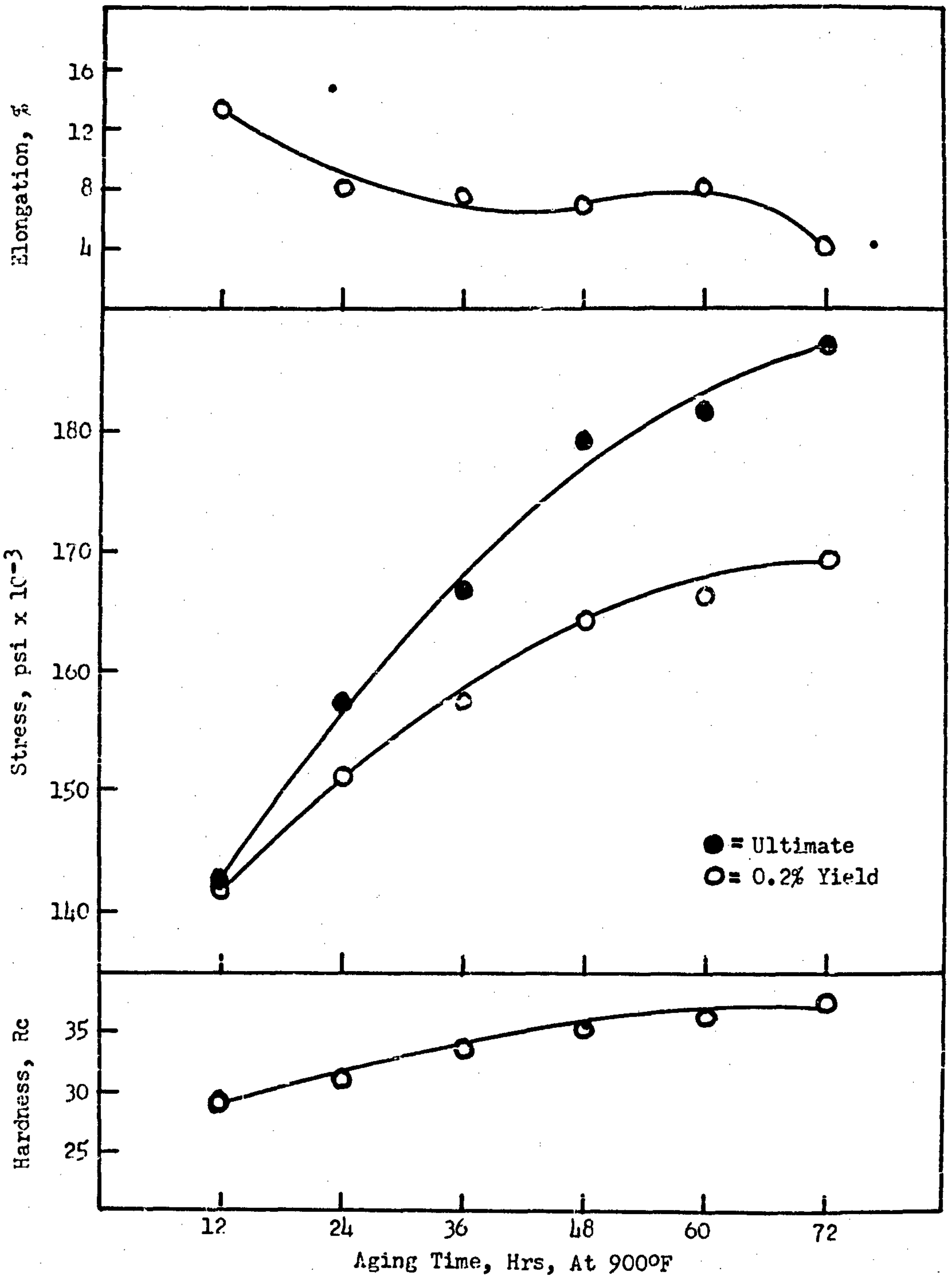
Mechanical Properties of PH 15-7 Mo Stainless Steel

Figure 11



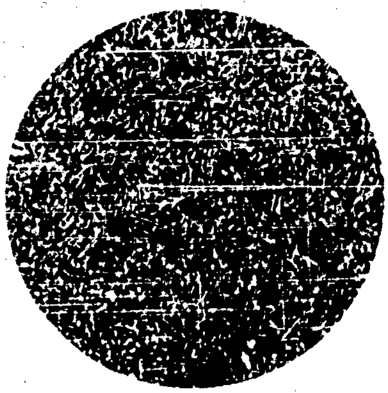
Mechanical Properties of B120VCA Titanium Alloy (Longitudinal)

Figure 12

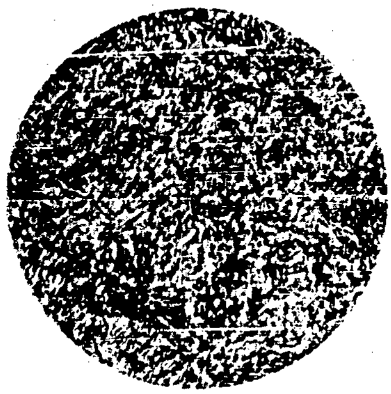


Mechanical Properties of B120VCA Titanium Alloy (Transverse)

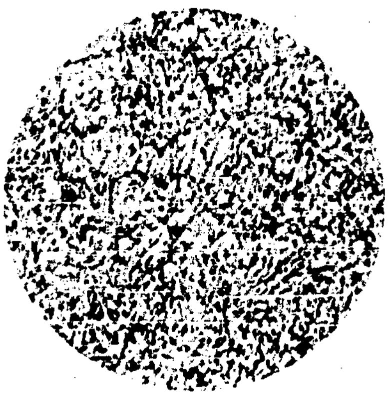
Figure 13



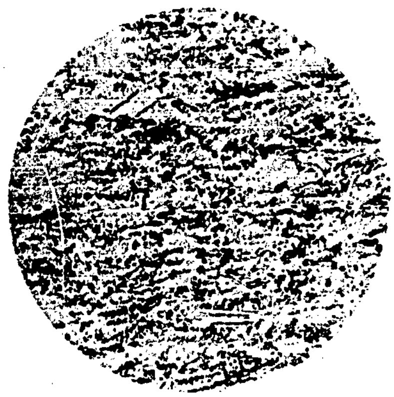
(a) Ladish D6AC



(b) Type 300M

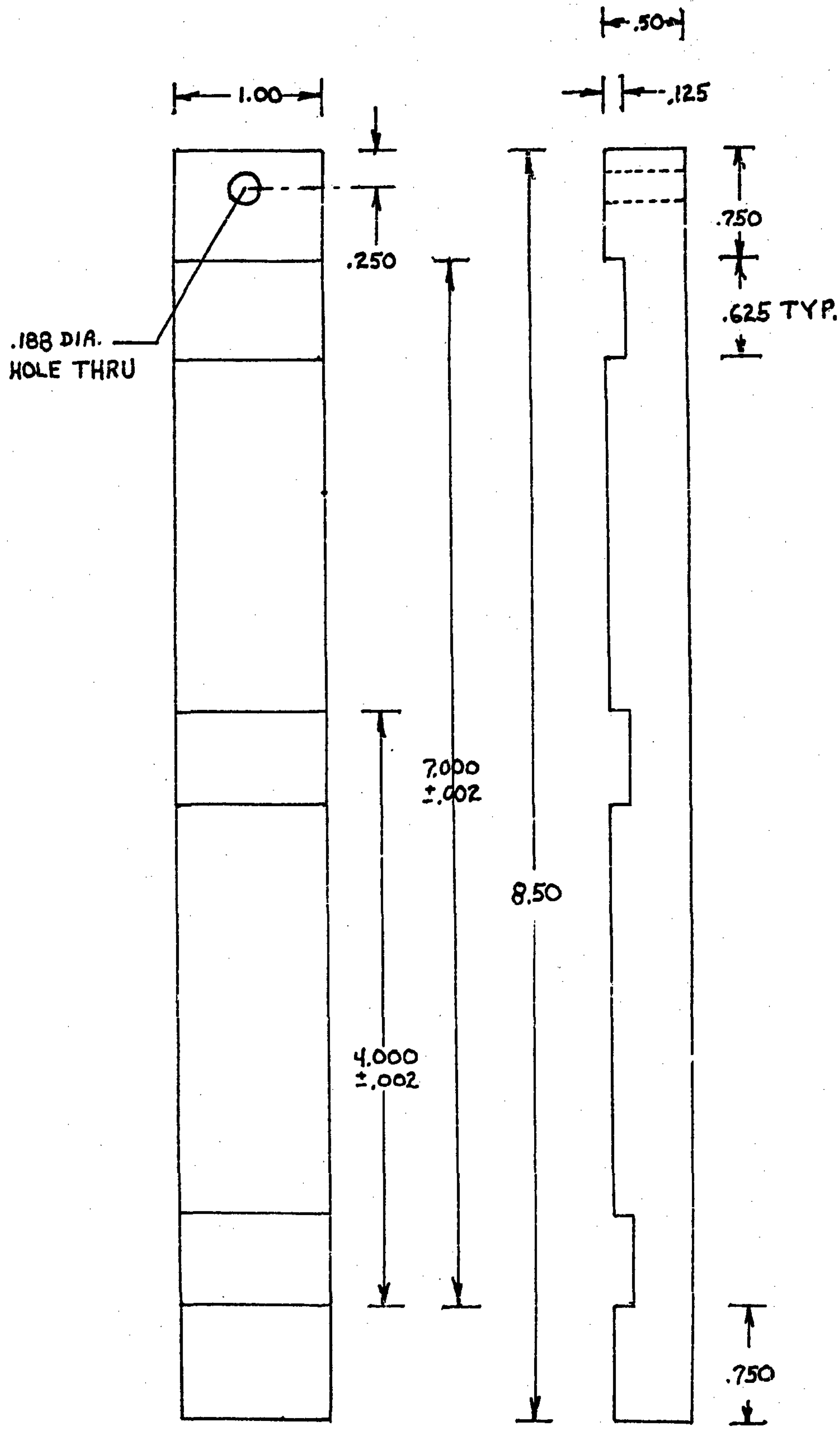


(c) Vascojet 1000



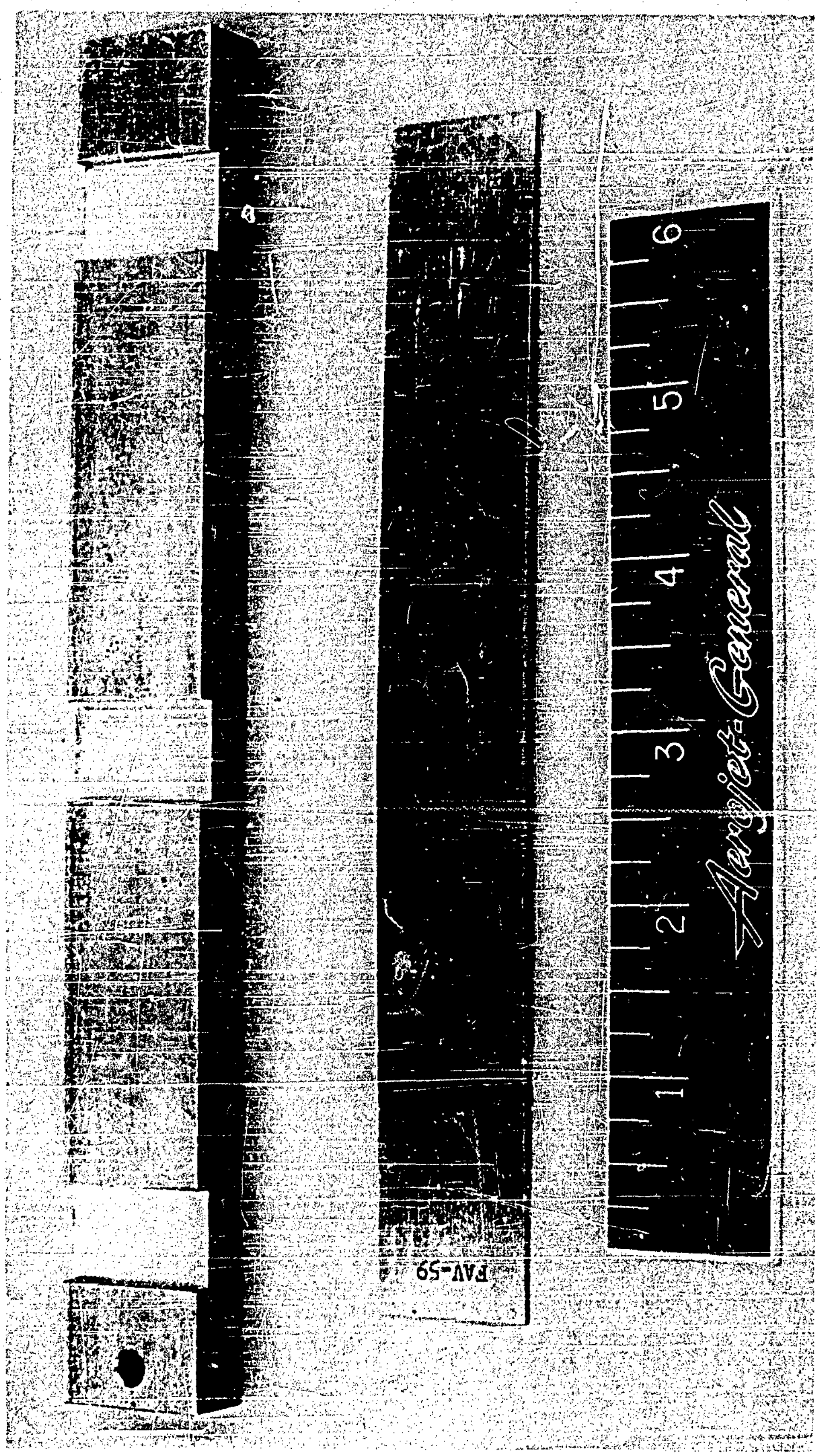
(d) AM355

Microstructure of Testing Alloys
Etch: 2% Nital Mag. 500x



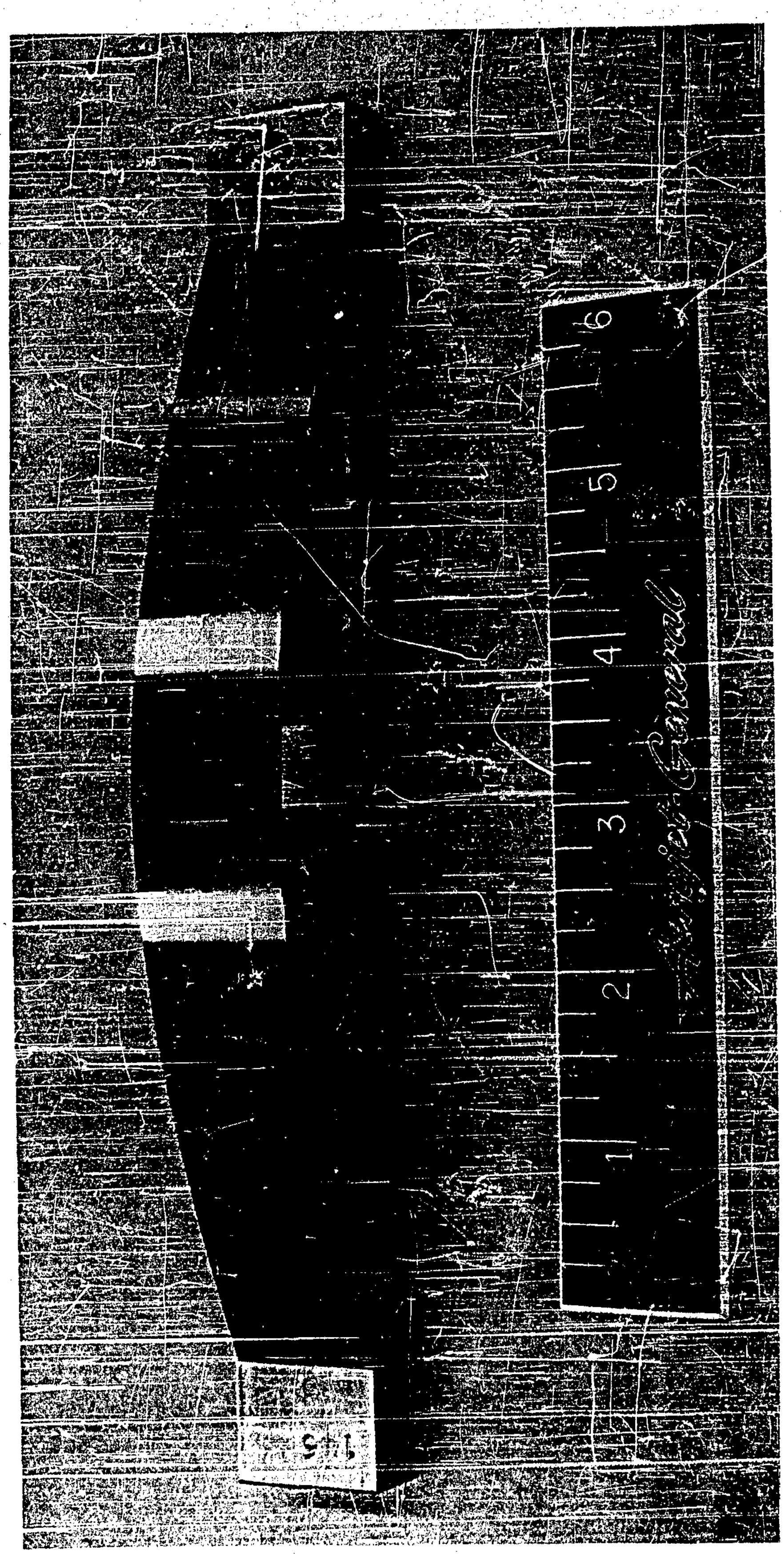
Schematic of Specimen Holder

Figure 15



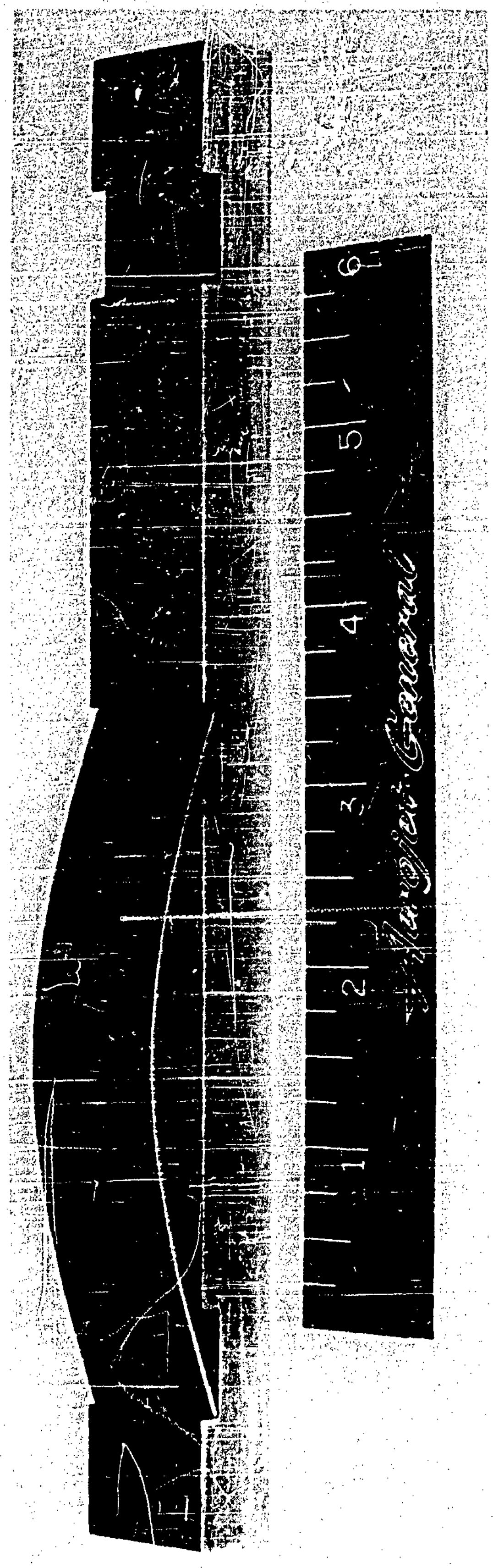
Test Specimen and Fixture Before Testing

Figure 16



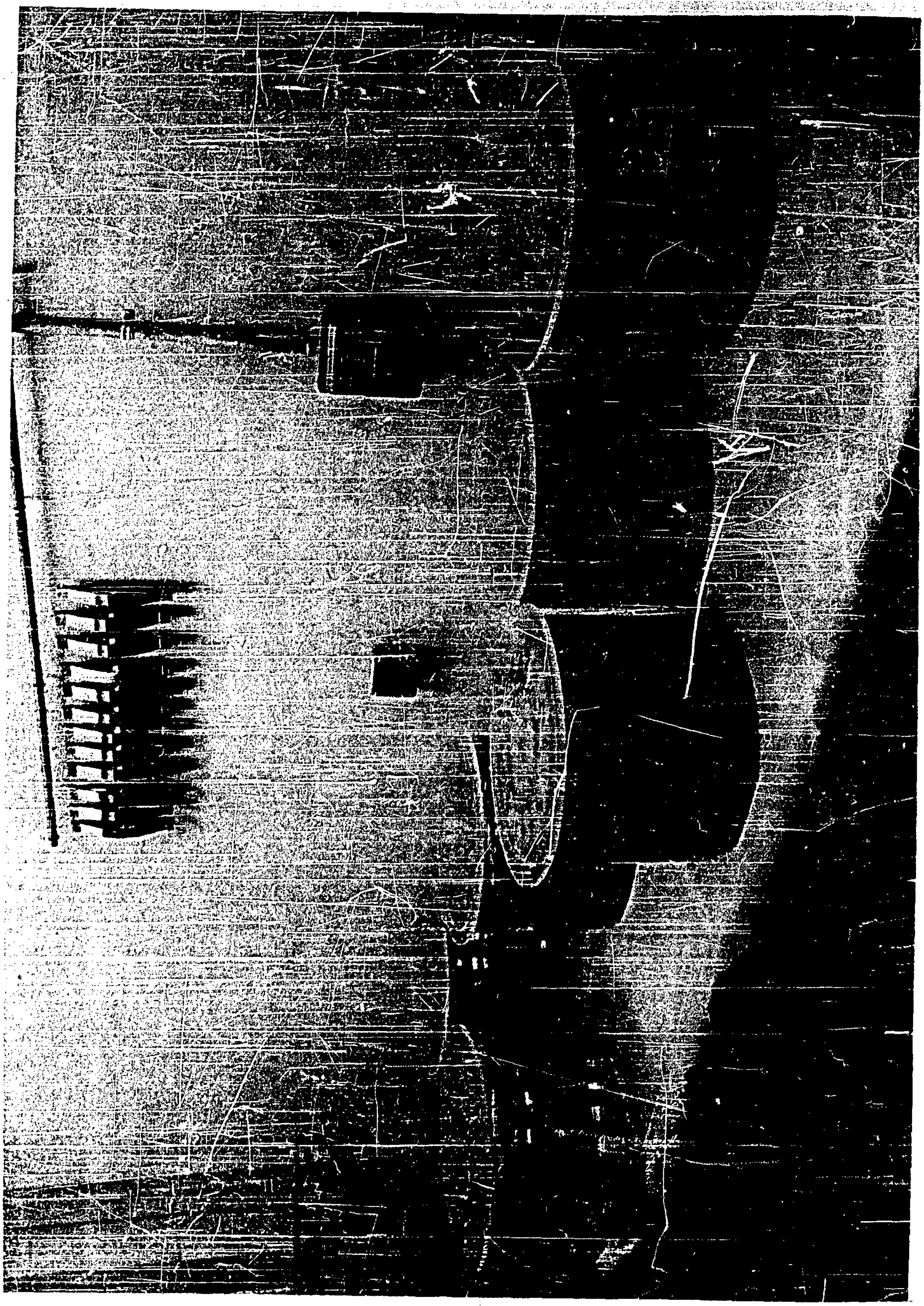
Test Specimen Stressed in Fixture Across 7.00-inch Span

Figure 17



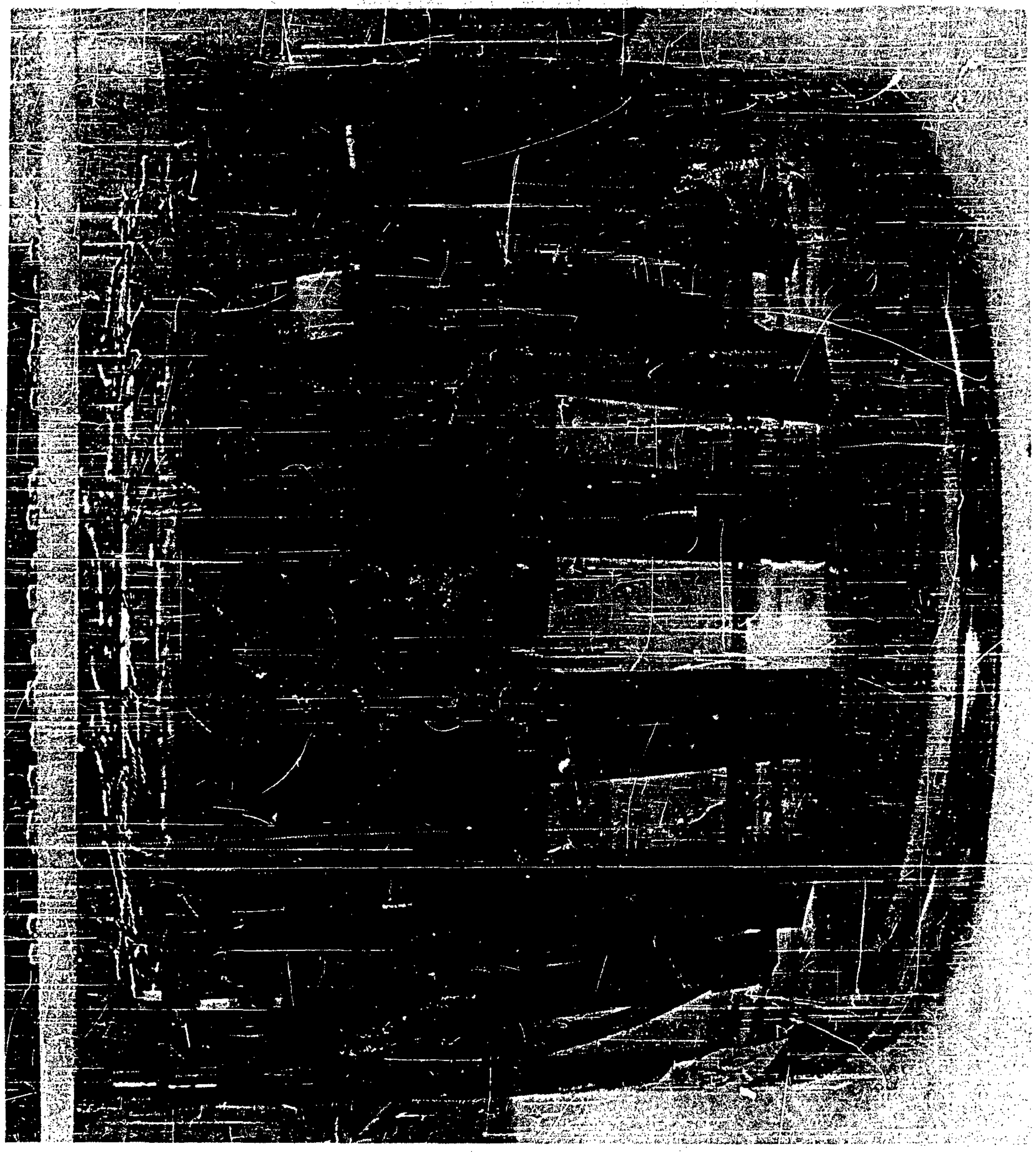
Test Specimen Stressed in Fixture Across 4.00-inch Span

Figure 18

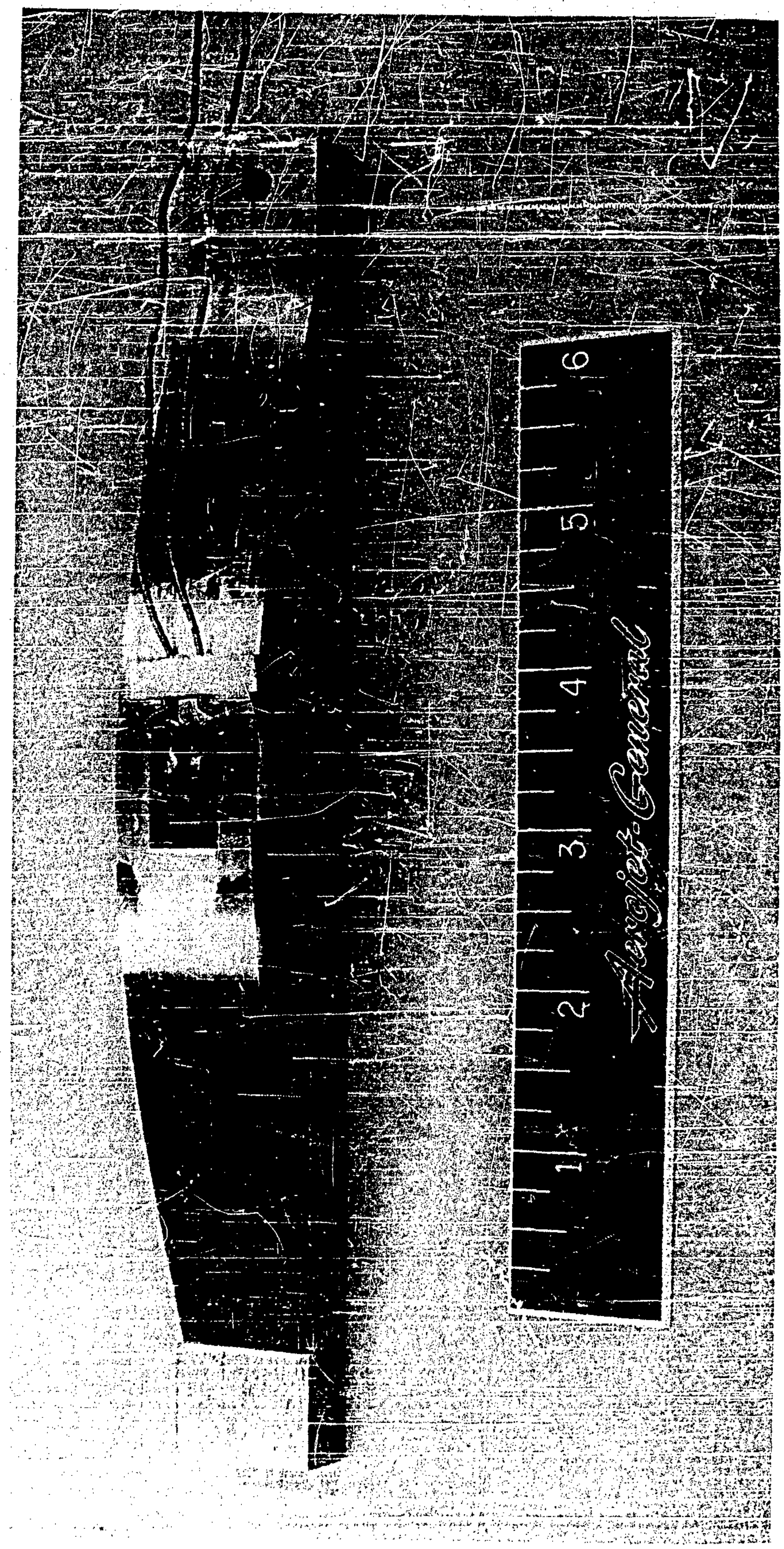


Environmental Stress-Corrosion Laboratory

Figure 19



Specimens Undergoing Environmental Stress-Corrosion Testing



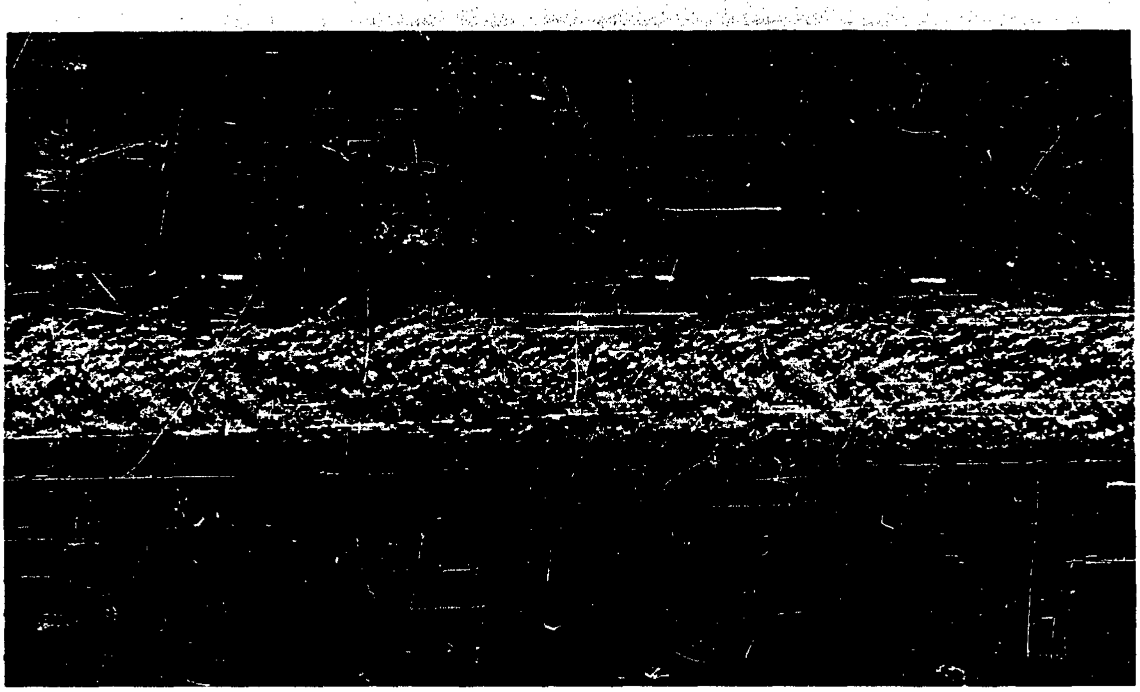
Test Specimen with Strain Gage Mounted, Stressed in Fixture

Figure 21

(A) (B) (C)

Vascojet 1000 Specimens After Failure

(A) Tap Water (B) Distilled Water (C) Salt Water



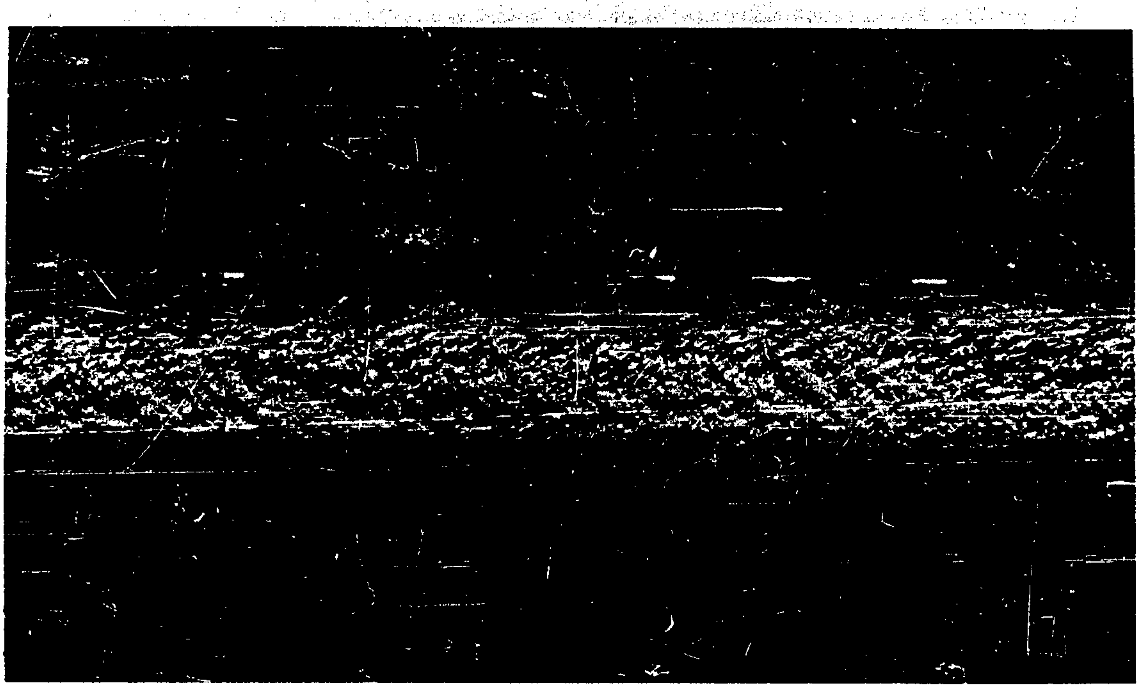
Fractured Surface of Failed Specimen, Mag. 15X

Figure 23

(A) (B) (C)

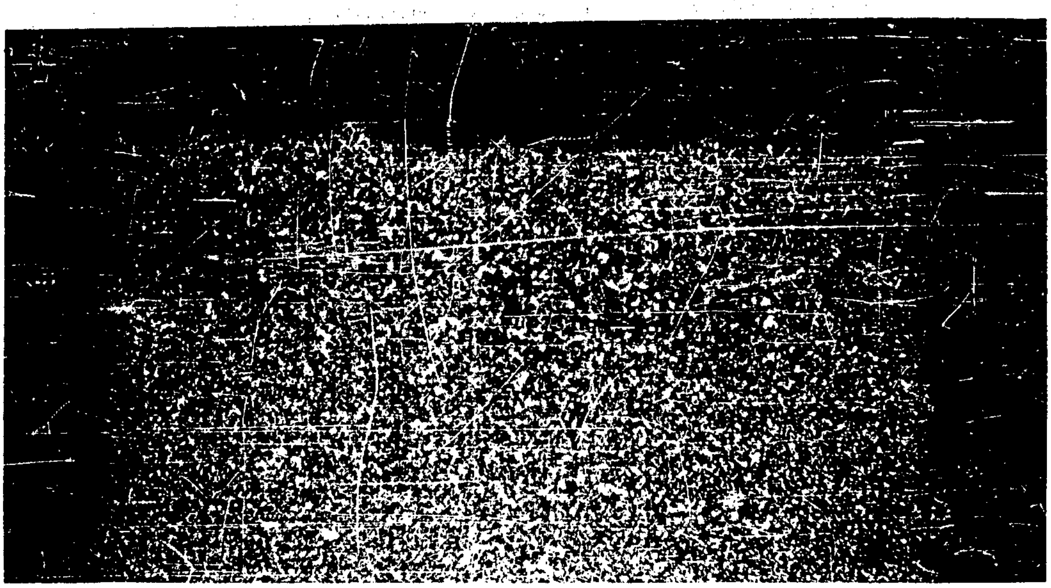
Vascojet 1000 Specimens After Failure

(A) Tap Water (B) Distilled Water (C) Salt Water



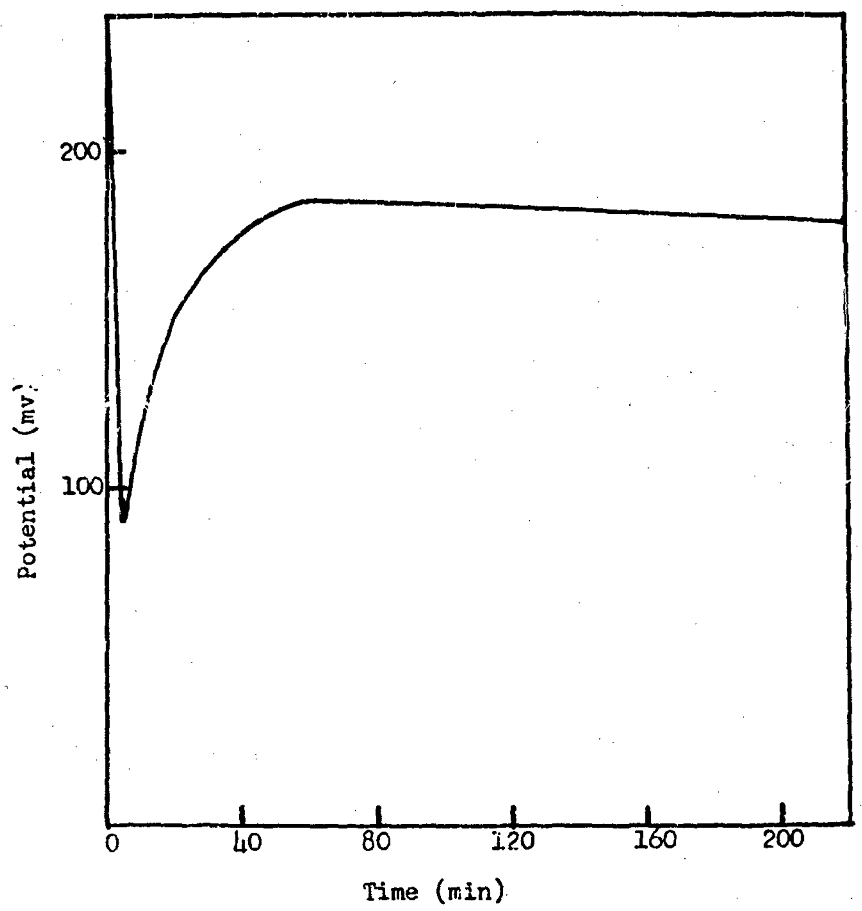
Fractured Surface of Failed Specimen, Mag. 15X

Figure 23



Cross Section of Fractured Surface
Etch: Picric+HCl Mag. 75X

Figure 24



Potential Between 304 Stainless Steel Specimen Holder and Vascojet 1000 Specimen in Tap Water

Figure 25

Report No. 2092

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